# Predictive Ecosystem Mapping

PEM

## User's Guide

March 2005

**Predictive Ecosystem Mapping User's Guide**
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**Prepared for: Tolko Industries Ltd.**
**Prepared by: Cortex Consultants Inc. and JMJ Holdings Inc.**

## Foreword

Predictive ecosystem mapping (PEM) is a type of expert system that has been applied to large-scale classification and mapping of ecosystems across British Columbia. It is seen by many as a useful alternative to the more costly terrestrial ecosystem mapping (TEM).

This guide provides an overview of PEM and its appropriate application to potential users—including resource management planners, timber supply analysts, systems ecologists, and habitat specialists.

## Acknowledgements

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This project was conceived by Tyler Mitchell and John Stace-Smith of Riverside Forest Products.

Cortex Consultants Inc. and JMJ Holdings Inc. developed the guide and accompanying workshop.

The project team is grateful for the support and direction received from the following individuals:

| | | |
|---|---|---|
| **Project Manager** | Nona Phillips | Nona Phillips Forestry Consulting |
| **Project Advisor** | David Moon | CDT Core Decision Technologies Inc. |
| **User's Guide Reviewers** | Dave Clark | Ministry of Sustainable Resource Management |
| | Corey Erwin | Ministry of Sustainable Resource Management |
| | Earl Spielman | West Fraser Mills Ltd. |
| | David Moon | CDT Core Decision Technologies Inc. |
| | Nona Phillips | Nona Phillips Forestry Consulting |
| **Technical Contributions** | Tim Bogle | Ministry of Forests |
| | David Carson | Timberline Forest Inventory Consultants Ltd. |
| | Dave Clark | Ministry of Sustainable Resource Management |
| | Tim Harding | Tolko Forest Industries Ltd. |
| | Colleen Jones | Ministry of Sustainable Resource Management |
| | Bob MacDonald | Ministry of Sustainable Resource Management |
| | Bob MacMillan | LandMapper Environmental Solutions Inc. |
| | Del Meidinger | Ministry of Forests |
| | David Moon | CDT Core Decision Technologies Inc. |
| | Phil Winkle | Decision Tree Forestry Consulting |

## Table of Contents

## List of Figures



## List of Tables

# 1 Introduction

## 1.1 Audience

The intended audience for the Predictive Ecosystem Mapping (PEM) User's Guide is professionals who are planning to use an existing or planned PEM inventory for a particular application such as wildlife habitat interpretations or estimates of site productivity. The audience includes resource management planners, timber supply analysts, systems ecologists, and habitat specialists.

The guide is intended to stand alone, as well as provide background reading material for the complementary workshop. It is **not** a technical reference for designing or carrying out a PEM inventory.

## 1.2 User's Guide Organization

This guide is organized around describing PEM and its uses, limitations, data requirements, and applications in British Columbia. Each section begins with an indication of learning objectives.

### 1.2.1 Content

**Section 2** describes the evolution of ecosystem mapping in British Columbia, and explains the range of inventories that can be included in the term *predictive ecosystem mapping*.

**Section 3** describes the types of PEM models, a framework for undertaking a PEM inventory, and critical assumptions. It also addresses the issue of suitability of an existing PEM inventory for a specific application, or conversely, the design requirements for PEM intended to be used for a specific application. Accuracy and reliability assessment are also addressed at the end of this section.

**Section 4** discusses possible applications of PEM inventories, such as timber supply analysis, wildlife habitat interpretations, biodiversity interpretations, and rare and special ecosystem inventories.

**Section 5** focuses on data types, format, and standards for PEM input and output data.

**Section 6** discusses limitations of PEM related to input data and modeling methods.

**Appendices** include acronyms and terminology, technical references, maps showing PEM projects across the province, and frequently asked questions (FAQs).

### 1.2.2 Conventions

Shaded notes to the reader are placed in the margin. Shading within the text is used to highlight examples.

*Italics* indicate a term that is defined in the glossary (Appendix 2) or legislation. **Bold text** indicates emphasis.

## 1.3 PEM Support

Appendix 5 provides URLs for sources of current information on PEM in British Columbia.

# 2 What Is PEM?

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On completing this section, users will understand:

- the basic elements of the BEC system
- the differences among ecosystem mapping, Terrestrial Ecosystem Mapping (TEM), Predictive Ecosystem Mapping (PEM), terrain mapping, bioterrain mapping, and biophysical habitat mapping
- the history of ecosystem mapping in British Columbia.

## 2.1 Background[1]

### 2.1.1 The Biogeoclimatic Ecosystem Classification System

Predictive ecosystem mapping in British Columbia is based on a conceptual model known as the Biogeoclimatic Ecosystem Classification (BEC) system, which was developed in British Columbia and is widely used as a framework for resource management and scientific research. The following excerpt of material from the BEC website[2] introduces the reader to the BEC system.

The BEC system groups ecosystems at three levels of integration: regional, local, and chronological.

At the **regional** level, vegetation, soils, and topography are used to infer the regional climate and to identify geographic areas that have relatively uniform climate. These geographic areas are termed biogeoclimatic units.

At the **local** level, segments of the landscape are classified into site units that have relatively uniform vegetation, soils, and topography. Several site units are distributed within each biogeoclimatic unit, according to differences in topography, soils, and vegetation.

At the **chronological** level of integration, ecosystems are classified and organized according to site-specific chronosequences. To do this, the vegetation units recognized for a particular site unit are arranged according to site history and successional status.

In order to arrange ecosystems at the three levels of integration, the BEC system combines four classifications: vegetation, climatic (zonal), site, and seral. Vegetation classification is most important to developing the ecosystem classification. However, the climatic and site classifications are the principal classifications used in the application of the BEC system. At this time the seral classification has not been adequately developed.

#### Naming BEC units

Biogeoclimatic zones are usually named after one or more of the dominant climax species in zonal ecosystems (the Alpine Tundra Zone is a self-explanatory exception), and a geographic (e.g., coastal, interior) or climatic modifier (e.g., boreal, montane). Biogeoclimatic zone names are

[1] Much of this material was extracted from the Ministry of Sustainable Resource Management TEM/PEM Website http://srmwww.gov.bc.ca/ecology/tem/index.html

[2] http://www.for.gov.bc.ca/hre/becweb/aboutbec/aboutbec-system-basic.htm

often referred to by a two- to four-letter acronym. For example, the Interior Cedar - Hemlock Zone is referred to as the ICH Zone and the Montane Spruce Zone is referred to as the MS Zone.

Subzone names are derived from classes of relative precipitation and temperature or continentality. The first part of the subzone name describes the relative precipitation and the second part describes either the relative temperature (Interior zones) or relative continentality (Coastal zones). For example, the ICH**mc** stands for the **M**oist **C**old subzone of the Interior Cedar - Hemlock Zone. Subzone names are abbreviated as letter codes (Table 2-1).

**Table 2-1 BEC subzone names and codes**

| | Name | Code |
|---|---|---|
| **FIRST PART:** | very dry | x |
| **Relative Precipitation** | dry | d |
| | moist | m |
| | wet | w |
| | very wet | v |
| **SECOND PART:** | hot | h |
| **Relative Temperature** | warm | w |
| **or Continentality*** | mild | m |
| | cool | k |
| | cold | c |
| | very cold | v |
| | hypermaritime* | h |
| | maritime* | m |
| | submaritime* | s |

* Coastal Douglas-fir (CDF), Coastal Western Hemlock (CWH), and Mountain Hemlock (MH) Zones only

Biogeoclimatic variants are given geographic names reflecting their relative location or distribution within the subzone. For example, the Interior Douglas-fir Dry Cool Subzone (IDFdk) has four variants: Thompson Variant, Cascade Variant, Fraser Variant, and Chilcotin Variant. Variant names are given number codes (e.g., ICHdk**1**), which in most cases reflect their geographic distribution within the subzone from south to north.

Forested site associations are named using one or two tree species, followed by one or two understory plant species present in the climax or late seral vegetation unit (plant association) on which they are based. While the species chosen for naming the site association are often abundant in the climax vegetation, less common but characteristic

species are sometimes used to ensure that the site unit has a unique name within the provincial classification.

Site series names use the same names as the site associations to which they belong, preceded by the appropriate biogeoclimatic subzone or variant name (or code). Zonal site units are always numbered 01. Non-zonal forested site series are numbered from 02 to 29 sequentially in order of driest to wettest moisture regime and secondarily in order of poorest to richest nutrient regime.

### Site Classification

Within any biogeoclimatic subzone or variant, a recurring pattern of sites occurs, reflecting the variety of site features and soil characteristics that occur across the landscape. These ecosystems are described by the site classification of BEC. Three units are formally recognized in the BEC site classification: site association, site series, and site type. Two other units, site phase and site variation, are not formally included in the classification, but may be used to further subdivide site series. Site association is the basic unit of site classification, but site series is the unit most commonly used by operational field staff.

A site association includes all ecosystems capable of developing vegetation belonging to the same plant association (or, in some cases, subassociation) at the climax or near-climax stage of vegetation development. In other words, a site association is a group of related ecosystems physically and biologically similar enough that they have or would have similar vegetation at maturity.

Since a site association can include ecosystems from several climates, it can be somewhat variable in its environmental conditions. Therefore, a site association is divided into site series within subzones and variants. Although a site association occurs on ecologically equivalent sites, the site series in it may occupy different positions on the scale of relative moisture and nutrients in different biogeoclimatic subzones or variants. For example, a site association that occupies sites that are relatively dry compared to others in a wet variant may be found in areas that are relatively wet compared to other sites in a dry variant.

Site series, then, are subdivisions of site associations and include all sites **within** a biogeoclimatic subzone or variant that are capable of producing the same mature or climax vegetation unit (plant association). Site series are described in the Regional Field Guides to Site Identification[3]. Site and soil conditions, and the vegetation community are used to identify site series.

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[3] http://www.for.gov.bc.ca/hre/becweb/publications-becpubslist.htm#RFG

### 2.1.2 Ecosystem Mapping

*Ecosystem mapping* is the stratification of a landscape into map units, according to a combination of ecological features—primarily climate, physiography, surficial material, bedrock geology, soil, and vegetation. Common scales of ecosystem mapping are 1:20 000 to 1:50 000, though larger scales such as 1:10 000 or 1:5000 may be used depending on project objectives.

Ecosystem maps, along with associated interpretations, supply valuable information for many applications related to the *Forest and Range Practices Act*, including landscape unit planning, Timber Supply Review, and range use planning. These maps also can be used to develop and apply the Biodiversity guidelines, the Riparian Management Area guidelines, and the Identified Wildlife Management Strategy.

*Terrestrial Ecosystem Mapping (TEM)* is a method of ecosystem mapping that relies on manual, as opposed to automated, application of relatively informal rules of interpretation, and is largely based on air photo interpretation and field checking. It is often, but not necessarily, used at large scales where detailed information is required. The usual TEM mapping unit is the *site series*[4] level of the biogeoclimatic ecosystem classification (BEC) system.

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Both TEM and PEM are methods of ecosystem mapping, rely on expert knowledge, and predict BEC variant and site series.

TEM relies mainly on manually applied, informally structured rules of interpretation.

PEM usually relies on computerized application of formally structured rules of interpretation (the knowledge base).

*Predictive Ecosystem Mapping (PEM)* is a method of ecosystem mapping that relies on computer automated, as opposed to manual, application of formally structured rules of interpretation (the so-called *knowledge base*). It usually does not involve air photo interpretation—instead, polygons are usually derived from other data sources such as forest inventory, soils, or bioterrain mapping. As with TEM, the usual PEM mapping unit is the BEC site series.

If PEM and TEM sound similar, it is because the distinction between them is somewhat arbitrary. Both TEM and PEM integrate biotic and abiotic ecosystem components of the landscape; both are based on expert knowledge; both predict occurrence of the ecosystem mapping unit[5]; and both allow valuable management interpretations to be made. The main difference is that PEM uses a formally structured set of interpretation rules (the knowledge base) and relies heavily on computer automation, whereas TEM uses a less formal set of interpretation rules that are applied manually. PEM ostensibly uses existing data rather than air photo interpretation of ecological units and field checking, but the

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[4] A site series encompasses all sites capable of producing the same plant community within a biogeoclimatic subzone or variant at maturity.

[5] The term predictive is used to indicate that the classification is based on the probability of a particular site series occurring at a specific location.

reliance of some PEM models on soils mapping or *bioterrain mapping* (see below) clouds this distinction.[6]

At one time, a method that relied on expert knowledge to classify or predict outcomes would have been called an *expert system*, but this term seems to have fallen out of favour in recent years. In the PEM type of expert system, combinations of input data (e.g., site characteristics such as BEC variant, slope and aspect) are assigned to specific interpretations (e.g., site series) by an ecologist with local experience and (or) using statistical relationships derived from plots. The rules of interpretation relating ecological characteristics to ecosystem classification are formally structured in the knowledge base.

*Terrain mapping* delineates and classifies surficial materials, landforms and geomorphological processes.

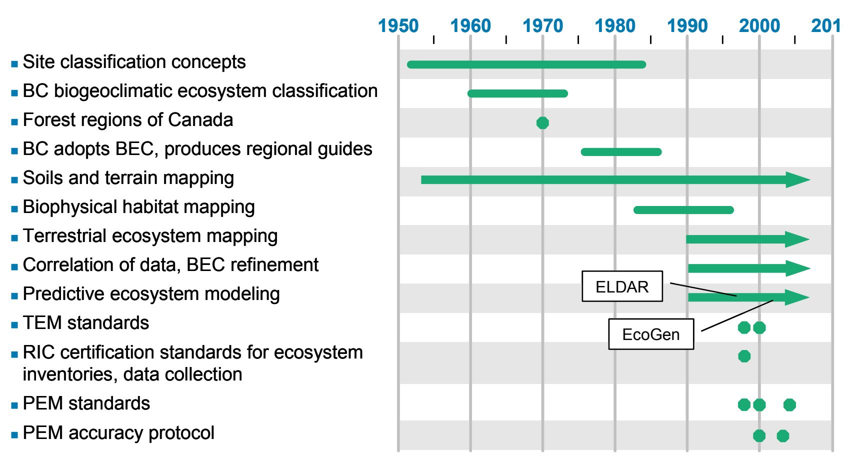
*Bioterrain mapping* utilizes the principles of terrain mapping as well as delineation of aspect and soil moisture classes in the surficial materials, landforms and geomorphological processes.

*Biophysical habitat mapping* is a precursor to TEM in which polygons are delineated from bioterrain mapping and ecosystems are identified within the bioterrain polygons.

### 2.1.3 Origins and Evolution of PEM

The classification and mapping of British Columbia's diverse ecosystems represent a significant effort over the past 50 years (Figure 2-1).

**Figure 2-1 Milestones in the development of ecosystem classification and mapping in British Columbia**




[6] We thank David Moon for helping sort out the distinction between TEM and PEM.

## Ecosystem Classification

The biogeoclimatic ecosystem classification (BEC) system, developed based on European approaches to vegetation ecology, integrates vegetation, site, and climatic parameters.[7] BEC has been modified through the years,[8] and the B.C. Ministry of Forests (MOF) adopted the BEC system as the basis for forest management in 1976. Over the subsequent decade, each forest region developed a standardized ecosystem classification system based on BEC, and produced regional "Field Guides to Site Identification and Interpretation."[9]

## Terrain Mapping

Soils mapping conducted by the federal department of agriculture began in the 1950s. Terrain mapping systems were also being developed, standardized, and implemented in British Columbia in the 1970s and 80s. Nuretin Keser of MOF Research Branch, pioneered the conceptual information-overlay approach eventually used in EcoGen and ELDAR.[10] His approach was based on two seminal publications in the evolution of PEM: Hans Jenny's *Factors of Soil Formation*[11] and Jack Major's concept of adaption to ecosystems (soil and vegetation = *f* [climate, relief, parent material, organisms, time]).[12]

## Ecosystem Mapping

Biophysical habitat mapping, developed in the 1980s,[13] delineated ecosystems using air photo interpretation, based on permanent

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[7] Krajina, V.J. 1969. Ecology of forest trees in British Columbia. Ecol. West. N. Am. 2(1): 1–146.

Krajina, V.J. 1972. Ecosystem perspectives of forestry. H.R. MacMillan Forestry Lecture Series. Univ. B.C., Cent. For Continuing Education, Vancouver, B.C., pp. 1–11.

Krajina, V.J. 1977. On the need for an ecosystem approach to forest land management. *In* Ecological classification of forest land in Canada and Northwestern U.S.A. Can. Inst. For., For. Ecol. Working Group, Univ. B.C., Vancouver, B.C., pp. 1–11.

[8] Meidinger, D. and J. Pojar (compilers and editors). 1991. Ecosystems of British Columbia. B.C. Min. For. Special Report Series No. 6. 330 p.

Pojar, J., K. Klinka, and D.V. Meidinger. 1987. Biogeoclimatic ecosystem classification in British Columbia. For. Ecol. Manage. 22:119–154.

[9] See, for example, DeLong, C. 2003. A field guide for site identification and interpretation for the southeast portion of the Prince George Forest Region. B.C. Min. For., Res. Br., Victoria, B.C. Land Manage. Handb. No. 51.

[10] D. Moon. 2005. Personal communication.

[11] Jenny, H. 1941. Factors of soil formation: a system of quantitative pedology. McGraw Hill, New York.

[12] Major, J. 1951. A functional, factorial approach to plant ecology. Ecol. 32:392-412.

[13] Demarchi, D.A., E.C. Lea, M.A. Fenger, and A.P. Harcombe. 1990. Biophysical habitat mapping methodology, first draft. B.C. Ministry of Environment, Wildlife Branch, Victoria, B.C.

landscape features of terrain at scales of 1:20 000 and 1:50 000. This classification was used to develop wildlife habitat interpretations.

The mapping of BEC site series evolved from biophysical habitat mapping, using the MOF standard nomenclature for ecosystems and the TEM system. TEM approaches and standards were adopted and the Resources Inventory Committee (RIC) developed the first certification for ecosystem inventories and ecological data collection in 1998.

### Ecosystem Modeling

As computing improved and became more cost effective, ecological mapping models were developed in western Canada as a low-cost surrogate for air photo interpretation based methods of ecosystem inventory. The Ecological Land Data Acquisition Resource system (ELDAR), a polygon-based method of spatial inventory, was developed by the Alberta Research Council and first tested in British Columbia in the McGregor Model Forest (Prince George) in 1994. The B.C. government supported the development of another polygon-based model as a low-cost alternative to TEM in the former Prince Rupert Forest Region in 1996. This model formed the basis of the present day EcoGen PEM model. During this time, remote-sensing researchers throughout North America and Europe were also developing ecological mapping models.

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By early 2005, about 15% and 53% of the province had been mapped with TEM and PEM, respectively.

Much of this mapping has been accepted in the provincial digital data warehouse managed by the Ministry of Sustainable Resource Management.

By 2001, various PEM models and projects were in progress throughout British Columbia, and RIC developed standards for mapping output and documentation. The first standards were published for publicly funded PEM projects in 1998, with subsequent standards released in 2000 and errata in 2004. A protocol to test the accuracy of mapping using independent data was developed in 2000 and 2003 by the MOF.[14]

By early 2005, about 15% and 53% of the province had been mapped with TEM and PEM, respectively (see Appendices 5, 6).

## 2.2 What Is a PEM Inventory?

A PEM inventory includes four output products or components:

1. site series polygon layer
2. site series attribute database, which contains for each polygon:
   - BEC variant

[14] Meidinger, D. 2003. Protocol for accuracy assessment of ecosystem maps. B.C. Ministry of Forests, Research Branch, Victoria, B.C.

   - deciles for site series
   - modifiers for slope and aspect (optional)

3. structural stage polygon layer
4. structural stage database

PEM and TEM produce essentially the same outputs, but they differ in how the outputs are produced and documented, and the consequent cost of production.

### 2.2.1 Comparing PEM to other inventories

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The shape of the PEM output polygon can be based on site series result, landscape shape, bioterrain, or forest cover.

Several types of ecological inventories are used in British Columbia (Table 2-1). Biophysical habitat, bioterrain, and TEM polygons are based on permanent landscape shapes formed from the deposition of materials by glaciation, water, wind, and gravity, and subdivided by directional exposure and BEC variant. Forest cover polygons are based on stand structure, species composition, age and height at the time of air photo interpretation; they are ephemeral shapes, reflecting a combination of the tree species and stand structure at the time of air photo interpretation, the history of the stand, and the growing potential of trees. Vegetation Resource Inventory (VRI) polygons can be based on either stand attributes or a combination of stand attributes and permanent landscape shapes derived from bioterrain. PEM models are based on the potential of the landscape to consistently give rise to a single site series or combination of site series. The shape of the PEM output polygon can be based on site series result, landscape shape, bioterrain, or forest cover.

**Table 2-1 Comparing ecological inventories used in British Columbia**

| **Inventory type** | **Thematic content** | **Photo interp.** | **Automated inference** | **Polygon shape derived from:** | | | **Application of inventory information** | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Bioterrain mapping | Site series mapping | Forest stand mapping | Wildlife habitat assessment | Engineering applications | Landscape unit planning | TSR | Riparian mgmt | Special ecosystems |
| **Biophysical habitat** | ecosystem structure | • | | • | • | | • | | | | | |
| **Bioterrain** | terrain classification, aspect, drainage | • | | • | | | | • | | | | |
| **Forest cover** | tree species, site productivity, structure | • | | | | • | • | | • | • | • | |
| **VRI** | tree species, other vegetation, coarse woody debris, other resource values. | • | | • | | • | • | | • | • | | |
| **TEM** | site series modified for slope and aspect, structure | • | | • | • | | • | | • | • | • | • |
| **PEM** | site series, structure | | • | • | • | • | • | | • | • | • | • |

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The focus of this guidebook is to explain how a PEM inventory works and how the PEM inventory could be used to support various applications.

### 2.2.2 Overview of PEM inventory applications

Ecosystem mapping is generally conducted to provide a basis for interpretations related to ecosystem-based, or sustainable natural resource management strategies. PEM output is very simple: the PEM spatial coverage usually depicts BEC *variant*, *site series* (or *map unit*, which could be a suite of site series), and may include modifiers for slope and aspect. The *stand structure* coverage of the PEM model can vary in format (depending on the interpretations for which it may be used); it usually identifies the dominant and secondary structural stages (bryoid, grass forb, shrub, pole sapling, young forest, mature forest, old forest).

PEM has been used with varying success in several applications in British Columbia; these are covered in more detail in Section 4:

- site productivity assessment for timber supply analysis, including Site Index–Biogeoclimatic Ecological Classification (SIBEC) (Section 4.1)
- wildlife habitat interpretations (Section 4.2)
- biodiversity interpretations (Section 4.3)
- rare and special ecosystem inventories (Section 4.4)
- riparian management area interpretations (Section 4.5)
- archaeological overview assessments (Section 4.6)

# 3 How PEM Works

## 3.1 Assumptions

PEM is based on three key assumptions:

1. The combination of climate, topography (or landscape), surficial geology, soils, water, vegetation, animals, and microorganisms, and the relationships among them give rise to predictable, mappable entities called ecosystems.
2. Relationships among the elements of nature that make up ecosystems can be generalized in an ecosystem classification system such as the BEC system.
3. Ecosystem maps can be interpreted in secondary analyses that can be used for natural resource management applications.

## 3.2 Raster and Vector Types of PEM Models

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On completing this section, users will understand:

- the differences between raster- and vector-based PEM modeling, and their significance to the final PEM inventory
- the framework and concepts underlying PEM modeling.

The variety of PEM models and types of spatial analysis used to produce PEM output, reflects both the ingenuity of PEM practitioners and the differences in context and input data found across the province. British Columbia has standardized its requirements for ecological classification, database, spatial data, and *meta-data*[15] used in PEM projects funded by provincial government agencies and initiatives. Regardless of the model used to generate ecosystem predictions, all publicly funded PEM models must be converted to the provincial standard vector format for storage in the provincial data warehouse.

All PEM models are based on either raster (grid) or vector (polygon) data models or a combination of both. However, discussions of the relative merits of raster- and vector-based models are largely esoteric. From the user's perspective, the most important issue is that the end product be usable. Conversion between raster and vector formats is simple and comprises an insignificant portion of project costs. The most obvious difference is the appearance of map boundaries (Figures 3-1 and 3-2). Lines in raster maps are jagged or "pixelated" (i.e., individual pixels or cells are apparent to the viewer). If smooth curves are important, spline functions can be used to transform raster maps into smooth curved vector maps with no measurable loss in spatial accuracy.

[15] Meta-data, or "data about data," describe the content, quality, condition, and other characteristics of the data of interest.

**Raster and Vector Data Models**

The rules used to convert real geographical variation into discrete objects is referred to as a data model—a set of guidelines for organizing the data in a database. The two main types of data model used in GIS are raster and vector.

In a **raster** model, the mapped area is divided into a regular grid of cells, in a specific sequence (usually row by row from the top left corner). Every location in the mapped area corresponds to a cell in the raster. Discrete objects are represented as single cells or groups of related cells.

In a **vector** model, the location of a discrete point in the mapped area is identified with reference to map coordinates. Discrete objects are represented as points (single locations), lines (groups of related points), or polygons (groups of related lines). A separate database contains the descriptive attributes of the objects, with an index linking each object to a record in the database.

Both types of input data can be used in either data model; raster can be converted to vector and vice-versa. The choice of data model is an issue for the model builder, since it affects the way in which data are used; it is of much less concern to the client who needs the site series predictions.

**Figure 3-1 In a raster data model, lines and polygons are generated from adjacent cells with the same attributes (indicated by colour in this example)**

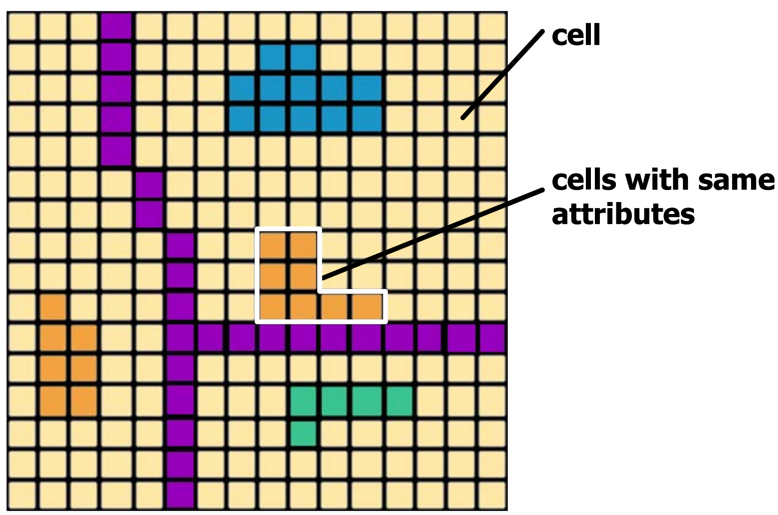
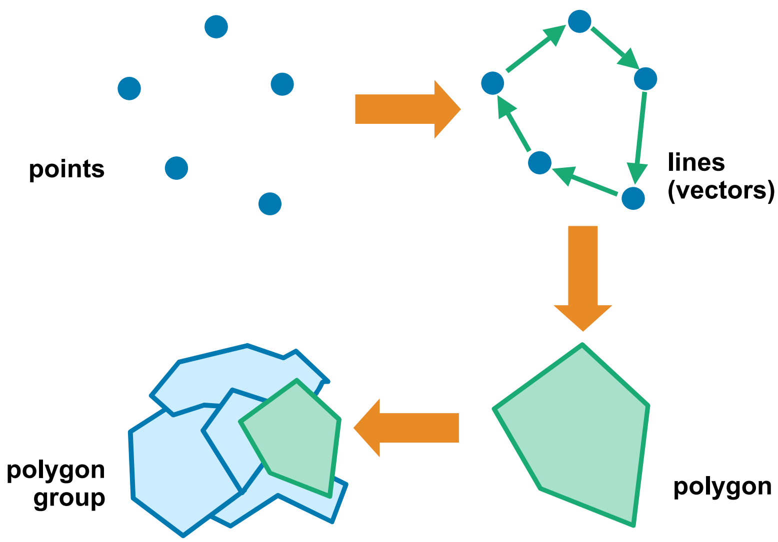


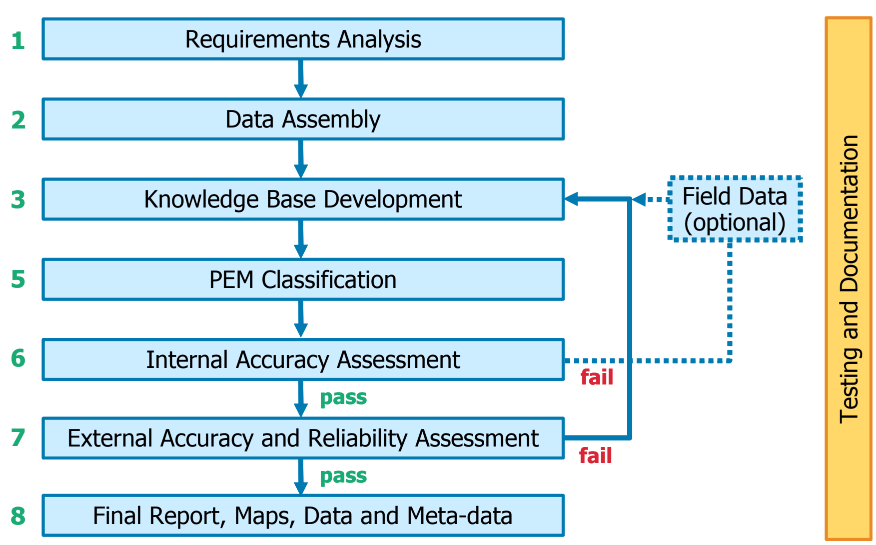
**Figure 3-2 In a vector or polygon data model, objects are represented as points, lines, or groups of related lines**




## 3.3 Modeling Framework for PEM

The PEM framework comprises eight main activities (Figure 3-3):

**Figure 3-3 The process for undertaking a PEM inventory.**



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The requirements analysis should include a clear statement of inventory objectives, a problem analysis to ensure that it is possible to meet the objectives, and a clearly defined set of procedures to meet those objectives.

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The knowledge base is the formal expression of the relationships between spatial input data variables and the site series classification.

1. Requirements Analysis (including Alternatives Assessment)

   Standard inventory procedures cannot answer all questions.[16] When initiating a PEM project, the client should determine whether PEM is the inventory needed to drive the required interpretations. Most important in the requirements analysis are a clear statement of the client's inventory objectives, a problem analysis to ensure that it is possible to meet the objectives, and a clearly defined set of procedures to meet those objectives.

2. Data Assembly and Assessment

   Spatial inventory data must be assembled and assessed for relevance to the PEM model. Evaluation of data quality is an important issue that should be considered early on, along with inventory procedures that affect data quality, and documentation of the input data.[17]

3. Knowledge Base Development

   In general, the knowledge base is the formal expression of the rules used to predict site series from ecological attributes; it comprises both the set of data tables mapping the relationships between ecological attributes and site series and the algorithms used to interpret the data and relationships to predict site series. The knowledge base can be developed in various ways, including using expert knowledge, analyzing plot data relative to input variables, or combinations of the two.

4. Field Data Collection

   There are at least three reasons for collecting field data:

   - to develop the model used to predict ecosystems
   - to test the ability of the model to predict ecosystems from correct input data
   - to test the accuracy of the model's predictions (predictive errors may be the result of inaccuracies in the predictive model and (or) inaccuracies in the input data).

   Field data must be collected to assess model accuracy, but is not necessarily required for developing the PEM model, which can rely

[16] Moon, D.E. and C.J. Selby. 1989. Land resources inventory of the Power River Watershed. Land Resource Research Institute, Agriculture Canada; CEF, Ottawa, Ont. Agriculture Canada Misc. Publ. No. 84-29.

[17] Moon, D..E., D. Dunlop, K. Iles, N. Phillips. 1999 Problem analysis on data quality assessment issues. Draft. Submitted to TEM Alternative Task Force by Core Design Technologies Inc.

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Quality control is normally the responsibility of the PEM practitioner. Quality assurance may be conducted by the practitioner (internal quality assurance) and (or) an independent third party (external quality assurance).

on existing data, expert opinion, or data collected in support of the PEM model.

5. PEM Classification

   The process of using the knowledge base to predict ecosystem occurrence from input data is referred to as classification. The spatial inventory data is combined with the knowledge base to produce a spatial depiction of site series and either a separate or linked depiction of stand structure.

6. Internal Accuracy Assessment

   Internal and external quality control, and assurance procedures and results should be documented.

   Quality control (ensuring that procedures are being followed) and quality assurance (checking for product quality) assess the results being achieved. Quality control is normally the responsibility of the PEM practitioner; quality assurance may be conducted by the practitioner (internal quality assurance) and (or) an independent third party (external quality assurance).

7. External Accuracy and Reliability Assessment

   Interpretations of legislative or policy issues may require assessment of map accuracy and reliability.[18,19] Note that it is the thematic information, rather than the location of polygons (linework), that is assessed here.

   Where PEM is to be used in the Timber Supply Review (TSR), an independent assessment of map accuracy and reliability is required (see Section 3.6). For use in TSR, at least 65% accuracy of the PEM map is required. Whether or not minimum accuracy levels are required to meet project objectives, mapping accuracy directly affects the reliability of an interpretation. The quality of an interpretation is a function of:

   - PEM accuracy,
   - sensitivity of the interpretation to PEM accuracy (i.e., errors in the PEM), and
   - accuracy of the predictive procedure.

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[18] Meidinger, D. 2003. Protocol for accuracy assessment of ecosystem maps. B.C. Ministry of Forests, Research Branch, Victoria, B.C. Technical Report 011.

[19] Moon, D.E., D. Dunlop, and N. Phillips. 2004. A protocol for assessing thematic map accuracy using small area sampling. Unpublished report to the Cariboo Site Productivity Assessment Working Group.

If an interpretation is not highly sensitive to errors in a PEM prediction, a map that failed a PEM accuracy assessment might still be used to produce relatively accurate interpretations. Conversely, if the PEM map does not provide all of the information needed for an interpretation, a highly accurate PEM map could cause large interpretation errors.

8. Final Report, Maps, Data and Meta-data

   The PEM process should be documented in a final project report, and in the meta-data of the deliverables submitted to the provincial PEM data warehouse.

## 3.4 Knowledge Base

The knowledge base of a PEM model relates variables from the spatial input data (Section 5.1) to the site series or map unit classification approved for use in the PEM model by the MOF Regional Ecologist.

The PEM practitioner and an ecologist with local experience build the knowledge base by assigning relative rankings to a matrix of site series and attributes. This process captures the ecologist's knowledge of the occurrence of site series on the landscape and applies it to the data in a consistent manner. [20]

◆
Knowledge bases can be structured many different ways, depending upon the individual PEM model.

Knowledge bases can be structured many different ways, depending upon the individual PEM model. A knowledge base may consist of rows and columns within a spreadsheet where each input variable, or combination of input variables, is assigned a value or weighting for a site series or group of site series (Table 3-2).

Some knowledge bases are simple, use very few variables, and have direct relationships between the variable and site series. Other types of knowledge bases infer relative relationships between spatial variables and the site series through cumulative scores, with the site series having the highest score being assigned to the spatial location of the appropriate combination of variables. That location could be an individual raster cell or a pre-determined polygon such as a bioterrain or forest cover polygon, or a subdivision of those polygons. Some practitioners have developed knowledge bases that use a combination of simple rules and *fuzzy logic* to classify *landscape facets* (spatial representations of combinations of landscape attributes) .

[20] http://www.for.gov.bc.ca/hre/ecogen/ecoprep.htm

**Table 3-2 Part of a knowledge base**

| Thematic input layer | Input layer class description | Site series number | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | **02** | **03** | **04** | **01** | **05** | **06** | **07** | **08** |
| | Crest | 10 | | | | | | | |
| Landscape position | Lower slope | | | | | 4 | 7 | 17 | 17 |
| Landscape position | Mid slope | | | 1 | 4 | 4 | 5 | | |
| Landscape position | Upper slope | | 1 | | 7 | 4 | 2 | | |
| Landscape position | Flat or valley bottom | | | | 10 | 5 | | 7 | 7 |
| TRIM | 0 to <5% slope | | | 2 | | 9 | 3 | 10 | 10 |
| TRIM | 5 to <25% slope | | | 2 | | 7 | | 2 | 2 |

The way in which a PEM model assigns a site series or combination of site series to a spatial location, whether cell or polygon, differs with the nature of the model. Some models assign a single site series or map unit to a relatively small area, others assign site series or map units proportionally to larger areas within an already existing polygon boundary such as a bioterrain polygon or a forest cover polygon. Some models determine the site series that "wins" (dominates) the cell or polygon and assign that unit to the model's output. Others assign a combination of site series to the cell or polygon based upon the first, second, and third place scores or weights from the knowledge tables.

Although the methods used to relate the spatial input variables to the site series or map unit vary with the model, all PEM models use a knowledge base define that relationship.

### 3.4.1 Derivation of Knowledge Base

Knowledge bases can be derived in different ways, depending upon the PEM methodology.

◆
Knowledge bases can be derived in different ways, depending on the PEM model.

The knowledge base scoring can simply be the product of expert ecological knowledge. Vegetation ecologists with a sound understanding of the ecology of the BEC subzones or variants within the project area arbitrarily determine the weighting of each spatial input variable to site series based on their understanding, experience or beliefs about the relationship between the site series classification and the input spatial data.

If the project area lacks extensive, spatially accurate field data where site series have been identified, then the expert knowledge approach can be used successfully and cost-effectively. Accuracy assessments of the Canim Lake and Quesnel PEM projects indicate that the use of a landscape approach based on expert knowledge of site series and

landscape relationships can be equal to or superior to knowledge bases trained with field data.[21]

If the project area has been field sampled, providing spatially accurate, ecologically reliable data describing site series (as part of the PEM project or from other initiatives within the project area), then those data can be summarized and compared with the spatial input data variables. If the sampling design was appropriate for the methods of analysis, statistics can be generated about the relationships between spatial input variables and the site series classification. These statistics can then be applied in the knowledge base to determine site series weighting for each spatial variable, or combination of spatial variables. This approach can be expensive for large project areas with many BEC subzones and variants if there is much field data collection.

### 3.4.2 Testing Knowledge Base

The knowledge base should be tested and improved until a satisfactory result is achieved. This iterative process can be undertaken using expert review, field data, or a combination of both (Figure 3-4).

#### Expert Review

In this process, a knowledgeable vegetation ecologist reviews the PEM model output and provides feedback to the PEM practitioner about the model and knowledge base to improve the output of the model. Once a satisfactory level of correspondence to the perceptions and experience of the ecologist is achieved, the model is finalized and tested for accuracy with independent data.

#### Field Data

If the PEM project has field data available for use in building the model, then the knowledge base can be tested using those data in various ways.

If the field data were collected with an appropriate sampling regime, then they could be summarized and the proportions of site series predicted by the model compared with the proportions of site series found by the field sampling. Then the knowledge base could be adjusted to produce a model result that, when summarized, predicts the same proportions of site series as do the field data. This may result in a model that can reliably predict site series proportions, but may not depict them accurately in the map.

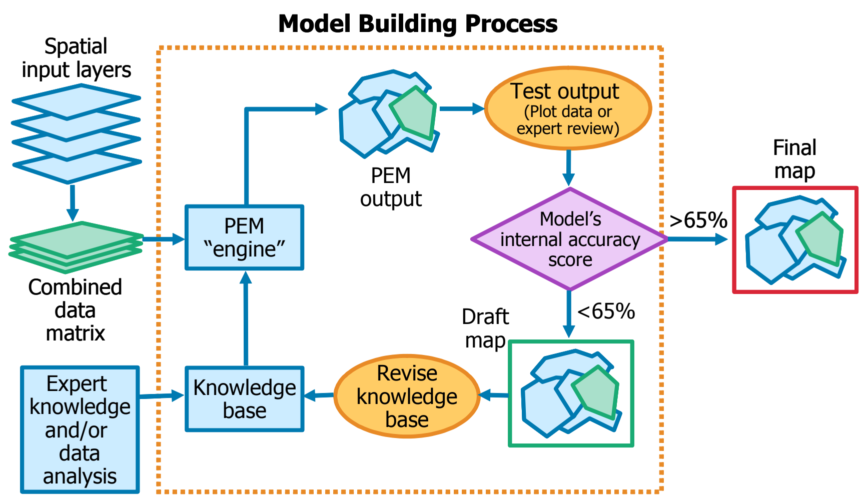
Field data can be used to train the model by comparing the site series found in the field at the UTM coordinate of each plot to that of the model at that location. This method must be used cautiously remembering that errors in input data and the knowledge base can result in the model

[21] Moon, D. 2005. Personal communication.

predicting site series in locations that are tens of metres away from their actual location. Field data should be distance buffered, or generalized to account for cumulative spatial errors.

The ecologist should examine field data relative to patterns of site series distribution on the ground. The knowledge base then needs to be adjusted to produce realistic depictions that, although perhaps not in the exact locations of the field data, result in site series patterns that bear a strong similarity to those found in the field.

**Figure 3-5 Knowledge base iterative development**




## 3.5 Assessing the Suitability of a PEM Inventory

Determining whether an existing PEM inventory is suitable for a particular application involves considering the specific requirements of the application and the characteristics of the PEM inventory. Tables 3-3 and 3-4 provide an overview of issues that should be considered when deciding whether to use PEM for various applications.

### Table 3-3 Criteria for evaluating PEM for a specific application

| | |
|---|---|
| **Accuracy and reliability** | Is the PEM sufficiently accurate and reliable for the interpretation? |
| **Basis of interpretation** | Is site series appropriate for the interpretation? |
| **Polygon size and complexity** | Will the interpretation be constrained by polygon size? |
| **Polygon complexity** | Will the interpretation be constrained by polygon complexity? |

### Table 3-4 Considerations when specifying PEM attributes for a specific application

| Application | Independent accuracy assessment? | Meets provincial data warehouse specs? | Complex or simple polygon output? | Complex or simple map entities? | Big BEC completed? | Bioterrain or targeted map inputs? |
|---|---|---|---|---|---|---|
| **Timber Supply Review** | Required, must exceed 65% | Required | Both | Simple | Required | Optional |
| **Wildlife habitat assessment** | Recommended | Required | Both | Simple | Optional | Optional |
| **Biodiversity objectives** | Recommended | Optional | Both | Either | Optional | Optional |
| **Riparian Management Guidelines** | Recommended | Optional | Both | Either | Optional | Advantageous |
| **Sensitive or "special" ecosystem inventories** | Recommended | Optional | Simple | Simple | Optional | Advantageous |
| **Archaeological overview assessment** | Recommended | Optional | Both | Either | Optional | Advantageous |

*map entity*: the thing that is mapped; in PEM it is site series

*simple map entity*: represents a single site series

*complex map entity*: represents a complex of more than one site series which cannot be differentiated by the model

*simple polygon*: a polygon in which there is a single map entity

*complex polygon*: a polygon in which there is more than one map entity per polygon

## 3.6 Reliability and Accuracy Assessment

To confidently use PEM for natural resource management applications, its *reliability* and *accuracy* must be determined.

Reliability, which comprises accuracy and precision, is the probability of a specific interpretation not being wrong. Accuracy is the closeness of a presented value to the true value. Precision is the exactness of measurements or predictions. Precision generally decreases as the requirement for accuracy increases and vice-versa.

The reliability required for any project is a function of the sensitivity of interpretive or predictive procedures, and the consequences of errors. If small changes in input values cause large responses in predicted values, the requirement for precision is high. Conversely, if large changes in input values cause small responses in predicted values, the requirement for precision is low. If the consequences of predictive error are low, the need for accuracy is low, whereas if the consequences of error are high, high accuracy is needed.

Some applications, such as the Timber Supply Review, require the PEM output to meet specified levels of accuracy determined by a third party using an independent data set. Many ecosystem mapping projects are funded through the Forest Investment Account. All FIA-funded projects must be completed in accordance with the applicable provincial Resources Information Standards Committee standards.

◆
**Reliability** is the probability of a specific interpretation not being wrong (e.g., a 100% accurate map can have low interpretive reliability if its content is inappropriate for the interpretation).

The B.C. MOF Research Branch[22] and Moon *et al.*[23] have developed protocols for accuracy assessment of ecosystem maps. There is interest in also making this level of accuracy a requirement for PEM to be used for wildlife habitat interpretation. Not every PEM project has a required level of accuracy, and not every PEM model developed meets all accuracy requirements.

Both TEM and PEM are used throughout the province by many different users for many different reasons. Assessing the thematic accuracy of each individual mapping project is a key component in the determination of the appropriate interpretative uses of the data. Any PEM or TEM intended for use in TSR timber supply applications must meet certain minimum map accuracy standards.[24]

[22] Meidinger, D. 2003. Protocol for accuracy assessment of ecosystem maps. B.C. Ministry of Forests, Forest Science Program, Victoria, B.C. Technical Report 011.

[23] Moon, D.E., D. Dunlop, and N. Phillips. 2004. A protocol for assessing thematic map accuracy using small area sampling. Unpublished report to the Cariboo Site Productivity Assessment Working Group.

[24] Meidinger, D. 2003. Ecosystem mapping accuracy and timber supply applications. http://www.for.gov.bc.ca/hre/becweb/pdf/PEMaccuracystatement2003.pdf This

The MOF has also adopted a standard procedure for the accuracy assessment of ecosystem maps. A standardized approach allows for the comparison of results between different projects and (or) areas of the province, and gives users a quantitative sense of data quality. The accuracy assessment protocol can be used as part of a quality assurance procedure and (or) as a component of quality control undertaken by a TEM or PEM practitioner.

Third-party contractors assess the accuracy of Resources Information Standards Committee (RISC) standard TEM and PEM project deliverables. The client is responsible for submitting (via accuracy assessment contractors) all applicable accuracy assessment documentation to the Province in accordance with the procedures outlined in the standards document.[25]

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document presents minimum map accuracy standards for the use of PEM and TEM in timber supply applications.

[25] Resources Inventory Committee. 2000.Standard for Predictive Ecosystem Mapping – digital data capture, version 1.0. Available from: http://srmwww.gov.bc.ca/risc/pubs/teecolo/pemcapture/assets/pem.pdf

# 4 PEM Applications in Resource Analysis

☞
On completing this section, users will understand:

- the variety of potential interpretations or applications for PEM inventories
- the ways in which PEM is used in different applications.

A wide range of resource management activities could draw upon ecosystem mapping for input into decision making. The two most commonly used applications for PEM are considered in detail in this section--timber supply analysis and wildlife habitat assessment. Other applications discussed include biodiversity interpretations, rare and special ecosystem interpretations, riparian area management, and archaeological overview assessments.

## 4.1 Timber Supply Analysis

This section discusses:

- timber supply analysis, and the use of estimates of site productivity in timber supply analysis
- the ways in which a PEM inventory can be used to estimate site productivity
- critical issues that should be considered when contemplating using a PEM inventory as input to timber supply analysis.

### 4.1.1 Introduction

The supply of timber is an important factor in planning and managing natural resources. It is a key component of the information considered by the provincial chief forester when determining allowable annual cut (AAC). Timber supply analysis is the procedure used to estimate timber supply, and to show how it changes with changes in assumptions about policies, management practices, and inventory data (Table 4-1). It also supports land-use planning processes such as development of Land and Resource Management Plans (LRMPs) and forest management planning (e.g., silviculture strategies, wildlife habitat management strategies).

### 4.1.2 Overview of Timber Supply Analysis

◆
***Timber supply analysis*** is a process of exploring how alternative forest management strategies and timber harvesting levels affect timber supply.

*Timber supply*, the rate at which timber is made available for harvesting, is a measure of the potential flow of logs out of the forest in cubic metres per year. Timber supply is not the same as the inventory of timber, which is measured in cubic metres. The inventory of timber represents the maximum amount that could be harvested at any given time.

Timber supply analysis is usually undertaken with a computer model. Regardless of the model used, and there are many to choose from, timber supply analyses always require the same basic types of input data:

landbase, forest inventory, timber growth and yield, and management practices and parameters. PEM information may be used in preparing the first three types of data (see Section 4.1.4).

### 4.1.3 Modeling Timber Supply

Timber supply analyses always follow the same basic procedure regardless of which model is used. After the initial gathering of data and documentation of assumptions, the analysis proceeds as shown in Table 4-1.

**Table 4-1 Steps in timber supply analysis to support AAC determination**

| | |
|---|---|
| **Step 1** **Categorize the landbase** | The productive forest in a management unit is separated into the portion that is available for harvesting (the timber harvesting landbase) and the portion that is unavailable or inappropriate for timber production. |
| **Step 2** **Assign management zones** | If management practices are not the same everywhere in the management unit, the unit is divided into zones in which different management objectives, requirements, and practices can be modeled (e.g., watersheds, wildlife habitat areas, recreation areas). |
| **Step 3** **Classify the forest inventory** | Forest stands are classified into units that are suitable for projecting the yields of timber. These classes, which are referred to as *analysis units*, are usually based on leading tree species and site productivity (e.g., spruce-leading stands with site index greater than 18 m). |
| **Step 4** **Project stand yields** | Stand yield is projected for each management regime to be applied to each analysis unit. These projections are represented as timber *yield tables* that show stand characteristics at different ages (e.g., timber volume per hectare, average stem diameter). |
| **Step 5** **Identify management activities and requirements** | Current management activities, including those that enhance timber production (e.g., planting, thinning), and those that maintain or enhance other forest values (e.g., wildlife habitat, visual quality), are identified. Management requirements and the area to which they apply are identified. |
| **Step 6** **Model the timber supply base case** | In each decade simulated, the model harvests available timber up to the target volume, and then "grows" the forest. The area available for harvesting each decade is limited by management requirements such as forest cover constraints and minimum harvest ages. |
| **Step 7** **Sensitivity analysis** | Sensitivity analysis is carried out to evaluate sources of uncertainty in the data and the management assumptions. |
| **Step 8** **Synthesis of results** | The TSR Timber Supply Analysis Report summarizes the information that was used in the analysis, states the base case harvest forecast, and synthesizes the results of the sensitivity analyses. |

### 4.1.4 Using PEM in Timber Supply Analysis

The main purpose of PEM inventories is to predict site series. In timber supply analysis the site series predictions are in turn used to estimate site productivity. Site productivity is usually represented in timber supply analysis with *site index*, which affects or is used in the first four steps of timber supply analysis (Table 4-2).

#### Site Index

◆
*PEM is used to predict site series, which are used in turn to estimate site productivity, a key input to timber supply analysis.*

Site index is used to represent site productivity based on the assumption that tree height accurately indicates growth potential.[26] Many factors other than site productivity may reduce height growth, confounding the reliability of tree height as an indicator of site productivity. As a result, site index estimates shown in forest inventory polygons are often inaccurate because they have been derived from measurements or estimates of stand or tree height and age. This is especially true for very young and vary old stands.

Various approaches to characterizing site quality directly from site characteristics have been explored in the literature for many decades.[27] In recent decades much effort has been devoted in British Columbia to investigating and developing methods of estimating site index based on ecological attributes of the site.[28] These methods include the Site Index–BEC (SIBEC) studies and the two approaches (veteran trees, paired-plot) used in the Old Growth Site Index (OGSI) studies.

The SIBEC studies estimate site index at the site-series level of the BEC system.[29] The SIBEC tables relate site index to BEC site series for coniferous tree species in British Columbia.

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[26] Clutter, J.L., J.C. Fortson, L.V. Pienaar, G.H. Brister, and R.L. Bailey. 1983. Timber management: a quantitative approach. John Wiley & Sons, Toronto, Ont.

[27] Carmean, W.H. 1975. Forest site quality evaluation in the United States. Adv. Agron. 27:209–269.

[28] British Columbia Ministry of Forests. 1997. Site index estimates by site series for coniferous tree species in British Columbia. Res. Br., Victoria, B.C.

______. 2001. SIBEC sampling and data standards. Version 5.1. Res. Br., Victoria, B.C.

[29] Mah, S. and G.D. Nigh. 2003. SIBEC site index estimates in support of forest management in British Columbia. B.C. Min. For., Res. Br., Victoria, B.C. Tech. Rep. 004.

**Table 4-2 Site index estimates derived from PEM site series and SIBEC are used in the first four steps of timber supply analysis**

| | |
|---|---|
| **Step 1**<br>**Categorizing the landbase** | One category of land that is not available for harvesting is land of low productivity, sometimes referred to as *low site*. They are considered unsuitable for harvesting and regeneration, and therefore excluded from the THLB. Site index is often used in the landbase netdown procedure to identify low site areas (e.g., hectares with site index < 6 m).<br>Since PEM is used to assign site index, which in turn is used to identify low site hectares, PEM comes into play in this early stage of preparing the data for timber supply analysis. |
| **Step 2**<br>**Assigning management zones** | If ecosystem type or site productivity is used to identify management zones, a PEM inventory can help with zoning the landbase, either directly through site series, or indirectly through site index. |
| **Step 3**<br>**Classifying the forest inventory** | If a PEM inventory is used to predict site series and estimate site productivity, it will directly influence the classification of the forest inventory. Since species and site productivity are the two most important parameters in the growth and yield models used to project yields for each analysis unit, the inventory classification must be based on them. |
| **Step 4**<br>**Projecting stand yields** | The most important application of PEM inventories in timber supply analysis is to estimate site productivity or site index for use in projecting stand yields. Site productivity is a key parameter in the yield models used to project stand yields (Figure 4-3).<br>The yield tables affect the estimate of timber supply both directly and indirectly. Since timber supply estimates are directly related to the area of the THLB and the yields expected for that area, the yield projections (and changes in them due to changes in site index) directly affect the volume available for harvesting. Yield tables also affect timber supply indirectly through their interaction with green-up ages and minimum harvest ages used in timber supply models (Table 4-3). |

**Table 4-3 Direct and indirect effects of yield tables on timber supply**

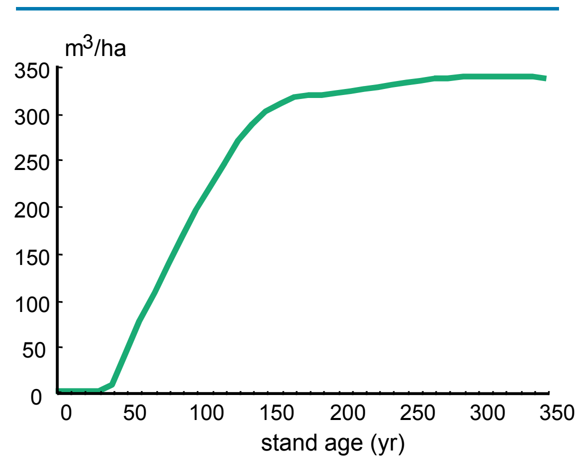
| Effects | Mechanism by which timber supply is affected |
|---|---|
| **Direct effects** | Yield table volumes directly affect volume available for harvesting. |
| **Indirect effects** | Age at which green-up height is reached affects the green-up or disturbance forest cover constraints used to represent visual quality and biodiversity requirements.<br>Age at which minimum harvestable volume per hectare or diameter is reached affects the minimum harvest age constraints, which determine when young stands first become available for harvesting. |

**Figure 4-3 Projecting yield for timber supply analysis**

**volume table**

| age | volume |
|---|---|
| 0 | 0.00 |
| 10 | 0.00 |
| 20 | 0.00 |
| 30 | 0.00 |
| 40 | 7.20 |
| 50 | 41.44 |
| 60 | 74.60 |
| 70 | 106.24 |
| : | : |
| : | : |
| 330 | 336.94 |
| 340 | 336.30 |
| 350 | 335.37 |

**yield curve**




### How Is PEM Used with SIBEC to Estimate Site Index?

Timber supply analysis requires an estimate of site index for every hectare. In the context of this guidebook, the process of estimating site index involves two basic steps: predict site series with PEM, and then look up the site index in the Site Index-Site Unit Report tables.

Assuming that a PEM prediction of site series is available for each forest polygon, we can proceed to using the Site Index-Site Unit Report tables to estimate site index as follows. Since site index differs by species for any site, the site index species must be chosen for each stand. The site index species is the tree species for which site index is estimated; the dominant species is usually used.

With zone, subzone/variant, site series, and species identified, the site index can be looked up in the tables of the Site Index-Site Unit Report by Biogeoclimatic Unit. If the polygon contains more than one site series, average site index should be computed, weighting by the amount of the stand area in each site series.

For more information on using SIBEC, refer to:
http://www.for.gov.bc.ca/hre/sibec/SIBEC_RDM_Section_6.htm

## 4.1.5 Critical Issues for Using PEM in Timber Supply Analysis

Timber Supply Review (TSR) has special requirements for using PEM because of the legislated responsibilities and obligations that accompany the determination of ACC. A third-party accuracy assessment is

particularly important in this context. The MOF Forest Analysis Branch has published standards for PEM accuracy assessment in TSR[30].

PEMs that have very few site series groups and few, if any, "tied", (equally likely) map entities mapped in polygons can be used in a fairly straightforward manner in conjunction with SIBEC estimates in timber supply modeling. PEMs with several to many site series groups (more than 1 pair per subzone/variant) or many tied site series mapped (greater than 10% of polygons with tied site series) cannot as a rule be used in timber supply modeling. If, however, the assignment of site index estimates to grouped and tied map units in a generalized PEM is reasonable, understandable and sensible, then the analysis may be acceptable to the Forest Analysis Branch.

If the PEM is rejected for timber supply analysis purposes (e.g., because it failed the accuracy assessment test), there may be alternative ways of estimating site index (e.g., the site index adjustment procedure). [31]

**Spatial Referencing**

The "debate" about the significance of *spatially explicit* timber supply analysis is mentioned here simply because it frequently distracts people from more important issues related to timber supply analysis.

One of the purposes of tactical and operational planning is to ensure that activities are scheduled to satisfy management requirements for block adjacency. Doing so requires a model that can recognize when treated areas are adjacent, and then constrain operations accordingly. This ability makes it possible to explore the effects of treatment timing, location, and patterns of stand development on timber supply. Such models are sometimes referred to as *area-based*, *spatially explicit*, or geo-referenced because they recognize the spatial relationships between treatment units (e.g., cutblocks).

Strategic planning most often uses an aspatial model, meaning that information in the database (e.g., forest class) is aggregated so that the locations of forest stands within the planning area are not tracked in the model. Strategic planning explores the "big picture" implications of different management strategies, without considering block-by-block how those strategies would play out on the ground—it is assumed that they could be implemented satisfactorily. Some models can incorporate forest cover constraints that approximate the effects of spatial management objectives such as adjacency rules. The strategic plan gives direction to more specific plans, such as tactical and operational plans, in which such details are considered explicitly.

[30] Meidinger, D. 2003. Protocol for accuracy assessment of ecosystem maps. B.C. Ministry of Forests, Research Branch, Victoria, B.C

[31] http://www.jsthrower.com/gy_prod

## 4.2 Wildlife Habitat Interpretations

### 4.2.1 Introduction

Ecosystem maps generated by PEM can be used to assist in the determination of wildlife habitats. Ecosystem mapping provides a consistent framework for looking at habitats of individual species or groups of species at both the coarse- and fine-filter levels.

◆
Ecosystem mapping offers a consistent framework for looking at habitats of individual species or groups of species at both the coarse and fine filter levels.

PEM output can be used in:

- rating wildlife habitat capability and suitability of individual species, which are based on the relative value of an ecosystem to seasonal life requisites for that species
- habitat supply models, to assist in the analysis and forecasting of habitats and ecosystems to inform decisions about sustainable resource use
- delineation of ungulate winter range (UWR)
- Identified Wildlife Management Strategy[32] accounts and measures for species and their habitats, many of which can be determined with the assistance of an ecosystem map generated by PEM.

### 4.2.2 Overview of Wildlife Habitat Assessment

#### Ungulate Winter Range

Ungulate winter range (UWR) is an area that contains habitat needed to meet the winter habitat requirements of an ungulate species. Identifying UWR is based on current understanding of ungulate habitat requirements in winter, as interpreted by the Ministry of Water, Land and Air Protection regional staff based on current literature, local knowledge, and other regional expertise. UWR is recognized under the *Forest and Range Practices Act* (FRPA) for the following species: mule and black-tailed deer, white-tailed deer, elk, moose, caribou, bighorn sheep, thinhorn sheep, and mountain goat. UWRs for these species have been established in many areas of the province. The confirmation and establishment of UWRs and related objectives across the province to support the FRPA is ongoing.

#### Identified Wildlife Management Strategy (IWMS)

Identified wildlife are species at risk and regionally important wildlife that the Minister of Water, Land and Air Protection designates as requiring special management attention under the Forest and Range Practices legislation. This includes endangered, threatened, or vulnerable species of vertebrates, invertebrates, plants, and plant communities.

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[32] http://wlapwww.gov.bc.ca/wld/identified/iwms2004.html

Regionally important wildlife include species that are considered important to a region of British Columbia, rely on habitats that are not otherwise protected under FRPA, and are vulnerable to forest and range impacts.[33]

Identified wildlife are managed through the establishment of wildlife habitat areas (WHAs), objectives for WHAs, and implementation of general wildlife measures (GWMs), or through other management practices specified in strategic or landscape level plans. WHAs conserve those habitats considered most limiting to a given species.

◆
Typically, wide-ranging species that are sensitive to landscape level changes need to be considered within strategic or landscape level plans.

Generally, identified wildlife provisions do not address habitat supply, habitat connectivity, and population viability and other issues such as access management. Such issues should be taken into account during strategic or landscape level planning. Species requiring consideration within strategic level plans are typically wide-ranging species that are sensitive to landscape level changes, such as badger, caribou, grizzly bear, Marbled Murrelet, Queen Charlotte Goshawk, Spotted Owl, and wolverine.

The IWMS species accounts describe the habitat of species to the level of Broad Ecosystem Unit, which are amalgamations of different groups of site series and may include many distinct plant associations.

#### Grizzly Bear and Caribou Habitat

Habitat use by grizzly bears and caribou is part of an information set that can be incorporated into spatially explicit forest harvesting models. The attributes of those habitats can be wholly or partially described at the BEC variant, site series and structural stage.

### 4.2.3 Modeling Habitat

#### Wildlife Habitat Ratings

The modeling of wildlife habitat includes a variety of approaches, some of which draw upon ecological mapping. One form of wildlife habitat modeling is the *wildlife habitat ratings* approach used by the Ministry of Sustainable Resource Management.[34] The ratings are based upon the concepts of habitat capability and suitability.

*Capability* is "the ability of the habitat under optimal natural conditions to provide life requisites of a species." *Suitability* is "the ability of the habitat in its current condition to support the species." The capability and suitability ratings are developed through literature review, field

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[33] B.C. Ministry of Water, Land and Air Protection. 2004. Accounts and measures for managing identified wildlife: Introduction V.

[34] Resources Inventory Committee. 1997. Standards for wildlife habitat capability and suitability ratings in British Columbia. Terrestrial Ecosystems Task Force, Ecosystems Working Group, Wildlife Interpretations Subcommittee, Victoria, B.C.

surveys, and local expertise. This information is summarized in a species account that identifies the species needs for each season of the year and includes reference to food, shelter, and reproduction (Table 4-4). The information in the species account is related to the BEC classification for the area of interest through a look-up table. Ecosystem mapping can then be used to spatially depict the habitat ratings by combining the look-up table and the ecosystem map.

**Table 4-4 Ecosystem structure-based wildlife habitat ratings for old growth dependent species**

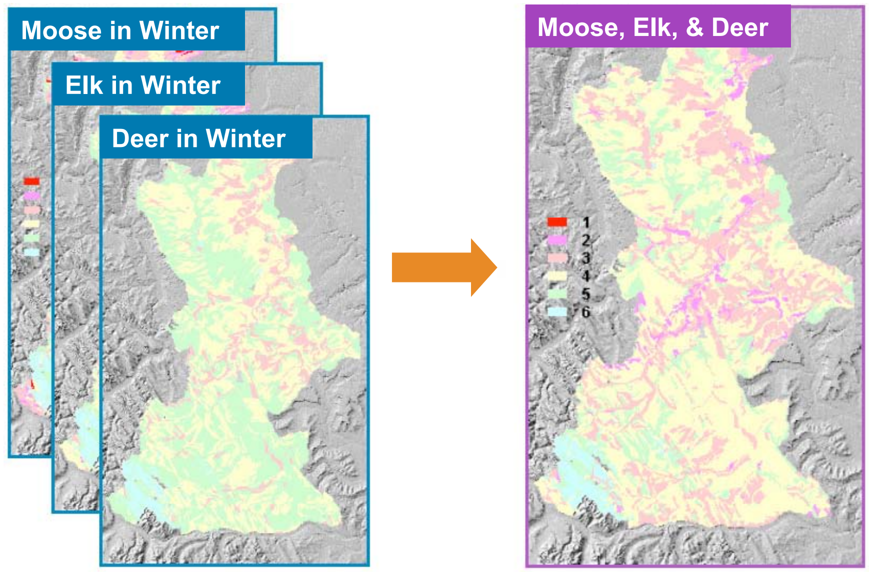
| Structural stage | Food | Security | Nesting |
| --- | --- | --- | --- |
| Shrub/herb | Low | Nil | Nil |
| Pole/sapling | Moderate | Low | Low |
| Young forest | Moderate | Moderate | Moderate |
| Mature forest | High | High | High |
| Old forest | High | High | High |

◆
Joining the PEM site series and structural stage databases to the wildlife capability and suitability ratings tables results in a map of wildlife habitat capability or suitability.

A PEM database can contain up to three site series for every PEM polygon. The habitat ratings database houses the capability ratings, by animal, activity, and season of use, in the look-up table. The rows of the look-up table represent the BEC variant, site series, and structural stage and the columns of the table rate the utility of that site series and structural stage to the seasonal use by the animal of interest. The ratings go from 1 through 6, with 1 representing the optimal habitat for that species and 6 representing a habitat of no use to the species for that activity and season.

Joining the PEM site series and structural stage databases to the wildlife capability and suitability ratings tables results in a map of wildlife habitat capability or suitability (Figure 4-4).

**Figure 4-4 Wildlife habitat capability for ungulate winter range; capability is rated on a scale of 1 (optimal) to 6 (no value)**




Source: Province of B.C.

## Habitat Supply Models

> ◆
> Habitat models are an abstraction of knowledge about habitat relationships. They represent and process this knowledge to predict future conditions.
>
> (Jones et al. 2001)

Habitat supply models predict habitat quantity, quality, and distribution, geographically and temporally.[35] They vary, and there are no standards for their use, format, and output. They are considerably more complicated than wildlife habitat ratings-based models, although certain habitat supply models may incorporate wildlife habitat capability or suitability ratings into their input data sets.

A habitat supply model can be used at both the coarse- and fine-filter levels. The coarse filter model can consider landscape-level habitat and (or) ecosystem-level habitat, and (or) stand-level habitat. The fine filter model can consider at its most detailed level the single-species guild-specific life requisites.

A habitat supply model may embellish the result of habitat ratings derived from an ecosystem map, or it may draw upon the ecosystem map alone to derive a result based on a combination of factors. Habitat supply models will often incorporate the results, or inputs to a timber supply model.

---

[35] Jones, K., R. Ellis, R. Holt, B. MacArthur, and G. Utzig. 2001. A strategy for habitat supply modeling for BC. Draft Volume 1. Prepared for Habitat Supply Modeling Steering Committee.

### 4.2.4 Using PEM in Habitat Models and Assessments

Spatial and database information generated by a PEM model can be used in habitat models and assessments. In capability/suitability models the BEC variant, site series, and structural stage information from the PEM database is related directly to the capability/suitability ratings via the wildlife habitat ratings tables. The result can be depicted as a map or used as a database. Then the capability/suitability information can be used to assist in the assessment of interpretations related to ungulate winter range or used as input in a habitat supply model.

The PEM ecosystem database and spatial coverage can also contribute directly to a wide variety of habitat supply models by providing an input layer, much as PEM uses other spatial inventories as input. Ecosystem can be one consideration in a habitat supply model; the spatial relationships among ecosystems are another factor considered by some habitat supply models. The effect of forest practices on habitat quality can be determined through a combination of ecosystem mapping from PEM and wildlife capability/suitability look-up tables in some habitat supply models.

PEM output, as found in the PEM data warehouse, is standardized and documented, which facilitates its use in a variety of habitat supply models.

### 4.2.5 Critical Issues for Using PEM in Habitat Analysis

◆
Critical issues for making PEM-based interpretations for habitat analysis:

- accuracy and reliability of the PEM model
- appropriateness for the species of interest
- suitability of the PEM polygons for use in the habitat model.

The following critical issues should be addressed when making PEM-based interpretations for habitat analysis:

- Accuracy and Reliability of the PEM model

  The PEM model output should have some stated measure of accuracy that can be related to the required reliability of the interpretations. Errors in the PEM model will be carried through the habitat analysis.

- Appropriateness for the species of interest

  The habitat requirements of the species need to be based on attributes of the PEM model. If the model does not provide the level of detail required to predict the habitat attributes, then it is inappropriate for the interpretation. For example, PEM output is not appropriate for the prediction of habitat use by carnivores unless it is somehow tied to the habitat requirements of the prey species.

- Suitability of PEM polygons for use in the habitat model

  If the PEM produces large, complex polygons it may be difficult to make meaningful habitat interpretations about entire polygons. How should one interpret critical habitat that is only proportionally

represented in a large polygon? For example, if the PEM output predicting map unit $X_7Y_2Z_1$ is superimposed on a different map input $A_6B_4$, how are the cross-products calculated, and which combinations occur in what proportions if the critical habitat is Z?

If the PEM produces small simple polygons, will the habitat model have the processing capability to use the spatial data? A difficulty could arise for example, if the processing capability of the habitat model was based on an average polygon of 12 ha, but the average PEM output polygon was 2 ha. The habitat model might have to be subdivided into several smaller areas for processing when the PEM data are added.

## 4.3 Biodiversity Interpretations

### 4.3.1 Introduction

◆
PEM mapping can be used to assist in establishing biodiversity emphasis options through the identification of the BEC variant, site series and structural stage relative to the natural disturbance type (NDT).

Biological diversity (or biodiversity) is the diversity of plants, animals and other living organisms in all their forms and levels of organization, and includes the diversity of genes, species and ecosystems, as well as the evolutionary and functional processes that link them.[36]

Developing a biodiversity conservation strategy that is based on various management strategies for individual species is neither feasible nor effective. The impact of forest management practices on many species is unknown and practices that benefit some species are often detrimental to others. Recommended instead is the development of an ecosystem management approach that provides suitable habitat conditions for all native species. Maintaining habitat diversity is used as a surrogate for maintaining biodiversity.[36]

Nevertheless, special efforts may be needed to protect the habitat of species known to be at risk, such as threatened, endangered, or regionally important species. Specific strategies for addressing these species are outlined in the Managing Identified Wildlife Guidebook. The conservation of biodiversity depends on a coordinated strategy that includes a system of protected areas at the regional scale, provision for a variety of habitats at the landscape scale, and management practices that provide important ecosystem attributes at the stand scale.

PEM mapping can be used to assist in establishing biodiversity emphasis options through the identification of the BEC variant, site series and structural stage relative to natural disturbance type (NDT). Within each NDT the present day seral stage distribution, riparian habitats, and

[36] B.C. Ministry of Forests and B.C. Ministry of Environment. 1995. Biodiversity guidebook. Forest Practices Code of British Columbia, Victoria, B.C. Forest Practices Code guidebook.

important wildlife habitats can be identified from the PEM structural stage and site series databases.

### 4.3.2 Overview

The more that managed forests resemble forests that were established from natural disturbances, the greater the probability that all native species and ecological processes will be maintained. PEM output can provide information on both the diversity of ecosystems found and the distribution of structures within those ecosystems at the time of mapping. PEM can then be used as a starting point for planning to maintain a variety of patch sizes, seral stages, and forest stand attributes and structures across a variety of ecosystems and landscapes. The juxtaposition of ecosystems and structures found in PEM output can assist in operational planning that maintains connectivity of ecosystems in such a manner as to ensure the continued dispersal and movement of forest- and range-dwelling organisms across the landscape.

PEM site series and structural stage output can also be used to assist in the identification of forested areas of sufficient size to maintain forest interior habitat conditions and to prevent the formation of excessive edge habitat. Riparian ecosystems can be recognized based on their local extent such that riparian buffers can be maintained and improved based on landscape shape rather than distance buffers.

### 4.3.3 Using PEM in Managing for Biodiversity Objectives

◆ PEM output can provide information on both the diversity of ecosystems found and the distribution of structure within those ecosystems at the time of mapping.

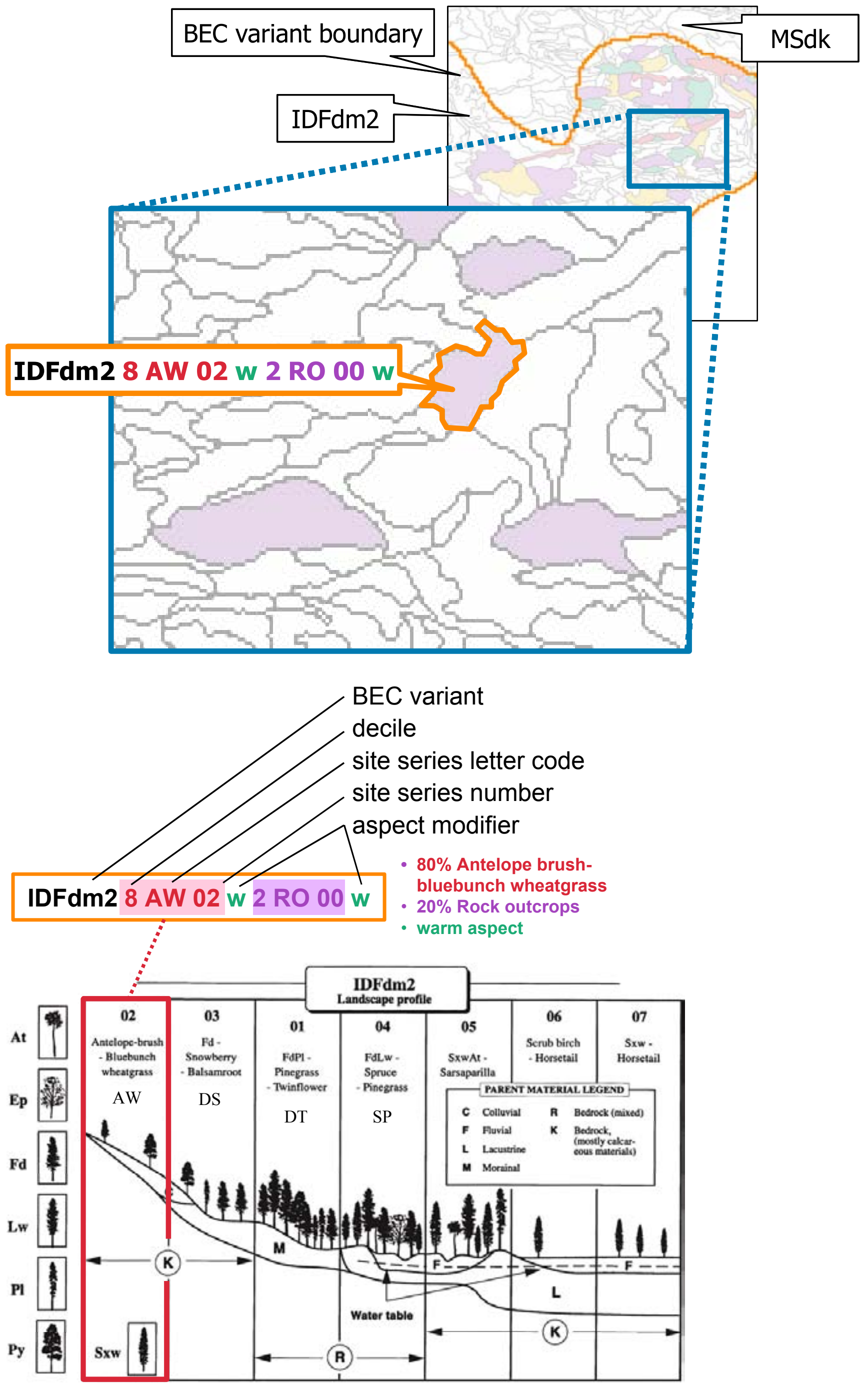
PEM output can be generalized into site series groups that summarize suites of related ecosystems that can be subjected to the same planning regimes. For example, in NDT 4 there is a requirement that a portion of the landscape be maintained in good condition as cattle range. PEM can be used to identify such candidate range areas (Figure 4-5).

The PEM structure model can also be used to identify areas of older structural stages that need to be considered in planning. These units can be combined with other synthesis products from PEM, TEM, or mapping that depicts ungulate winter range, critical grizzly habitat, or other critical habitats. This information may be combined with other spatial planning tools to depict the areas constrained for operational forestry.

**Maintaining Rangeland**

The IDFdm2 BEC Variant is NDT 4, characterized by historically frequent and widespread stand-maintaining fires. One biodiversity objective in this NDT 4 variant is to maintain at least 85% of it as permanent rangeland. Site series 02 (Antelope brush-Bluebunch wheatgrass) could be targeted as an ecosystem appropriate for range area retention by using PEM output.

**Figure 4-5 Using PEM to identify potential range areas in NDT 4**



### 4.3.4 Critical Issues for Using PEM to Help Manage for Biodiversity Objectives

◆
Critical issues for using PEM in management for biodiversity objectives:

- PEM accuracy and reliability
- Synthesis of the BEC site series classification into realistic planning units.

The critical issues around using PEM as part of an analysis to assist in meeting biodiversity objectives are:

- PEM accuracy and reliability

Applying biodiversity objectives at the landscape unit level based on unreliable or inaccurate ecosystem and structural-stage mapping could result in the biodiversity plan having erroneously interpreted objectives, poor locations for forest ecosystem networks, or inappropriate stand structure objectives.

- Synthesis of the BEC site series classification into realistic units for planning

The detail in PEM is often generalized by grouping site series into units with similar general ecosystem attributes appropriate for similar biodiversity objectives.

- Scale of PEM mapping relative to the level of objectives

PEM is generally produced for 1:20,000 or 1:50,000 scale output.

☞

Limitations to using PEM with rare or special ecosystem inventories are in the resolution and accuracy of the PEM.

## 4.4 Rare and Special Ecosystem Inventories

*Rare ecosystems* are defined as ecosystems that are listed as red or blue by the Conservation Data Centre[37] of the Ministry of Sustainable Resource Management. Special ecosystems are those that may be considered rare or unique, uncommon, interesting, sensitive, or of concern.

PEM output and (or) modeling approaches have been used to predict the spatial location of rare or special ecosystems (Figure 4-6), with varying degrees of success, depending on the quality of the input data.[38] Many of these ecosystems occur within small areas and are difficult to model.

This activity should not be confused with the Sensitive Ecosystem Inventory[39] (SEI), which requires air photo interpretation and specialized forms of terrain mapping. SEI procedures are generally not applicable to PEM modeling activities.

Limitations to using PEM with rare or special ecosystem inventories are in the resolution and accuracy of the PEM. The input data may not provide enough information to predict the location of these areas. The reliability and scale of input data must be carefully considered before using PEM for this interpretation.

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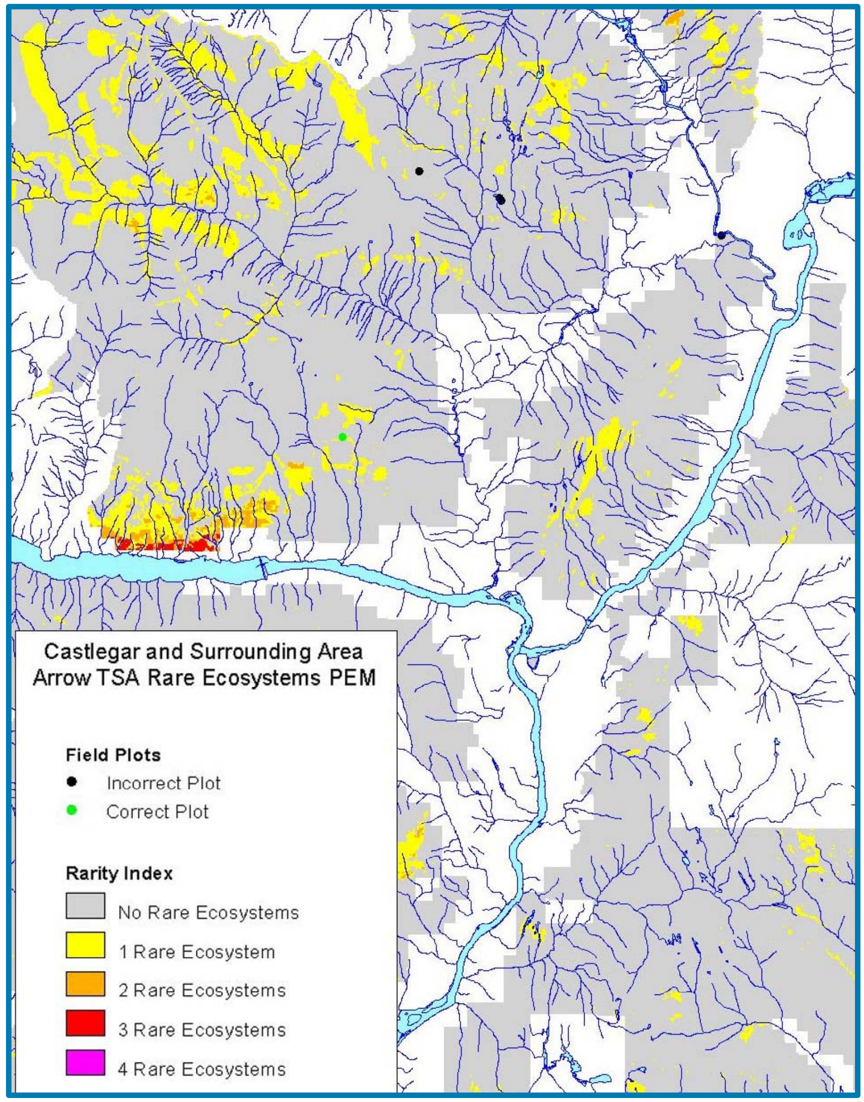
[37] http://srmwww.gov.bc.ca/cdc/

[38] Ketcheson, M., T. Dool and, and C. Littlewood. 2002. Development of procedures for mapping special ecosystems in the Arrow Timber Supply Area. Unpublished report to B.C. Ministry of Forests, Research Branch, Victoria. B.C.

[39] http://srmwww.gov.bc.ca/sei/

**Figure 4-6 Using PEM to delineate areas that may support rare or special ecosystems**




Source: JMJ Holdings Inc.

## 4.5 Riparian Management Areas

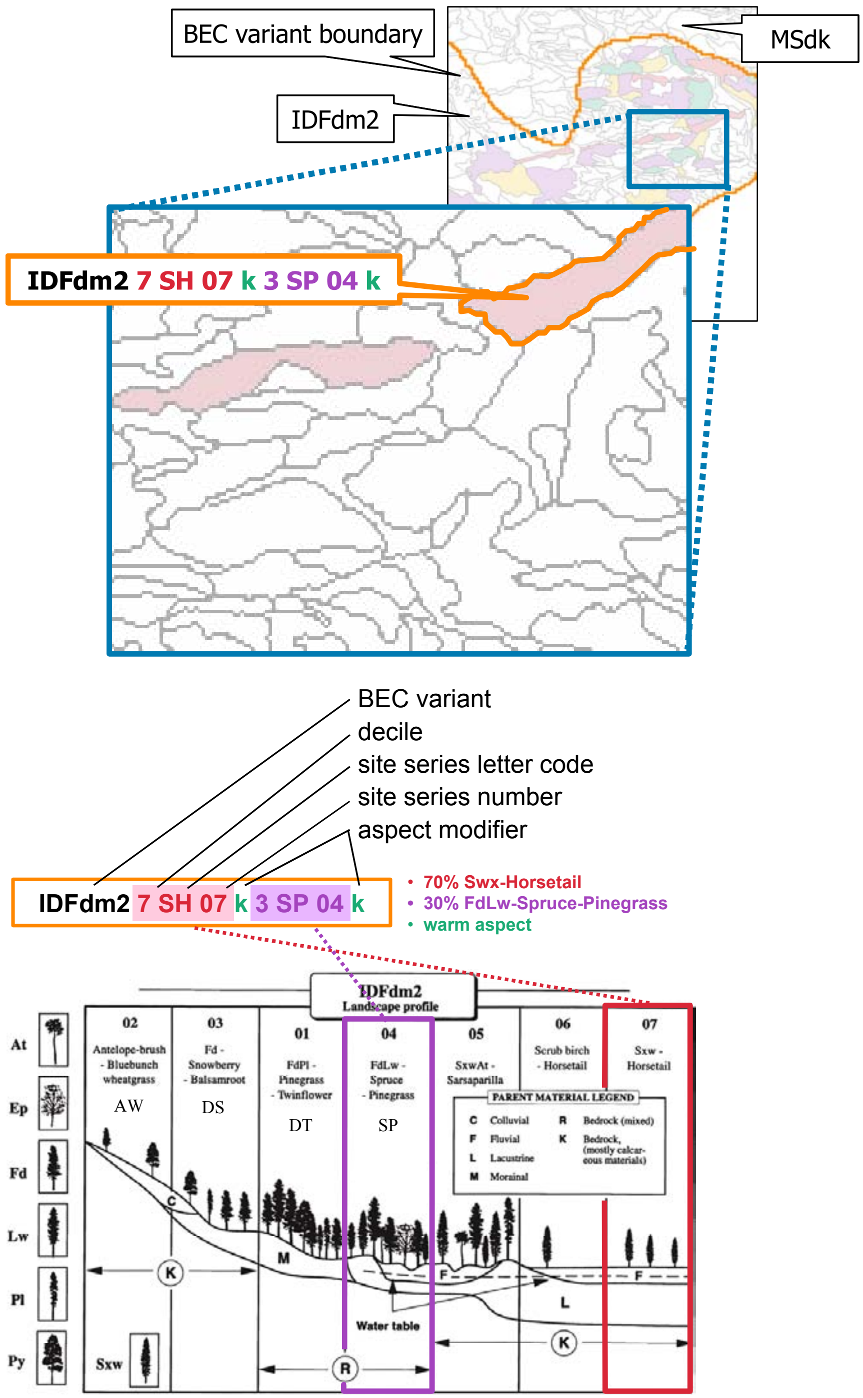
PEM can assist in the delineation of Riparian Management Areas (RMAs).[40] The PEM output can identify features of the riparian area that can be used to assist in meeting the objectives of the RMA (Figure 4-7). The outer edge of the active flood plain can be determined from the bioterrain input layer. Wetlands are identified in PEM and, depending upon the site series classification, can be classified into simple and complex wetlands. Riparian ecosystems used for grazing can be identified from PEM output.

☞ Carefully consider the reliability and scale of input data before using PEM for RMA interpretations.

The limitations to using PEM to assist in the delineation of RMAs are based in the resolution and accuracy of the PEM. The input data may not provide enough information to be used to predict the location of these areas. The reliability and scale of input data must be carefully considered before using PEM for this interpretation.

[40] B.C. Ministry of Forests and B.C. Ministry of Environment. 1995. Riparian management area guidebook. Forest Practices Code of British Columbia, Victoria, B.C. Forest Practices Code guidebook. http://www.for.gov.bc.ca/tasb/legsregs/fpc/fpcguide/riparian/

**Figure 4-7 Using PEM to delineate riparian ecosystems—70% of the target polygon supports a riparian ecosystem, Spruce-Horsetail**



## 4.6 Archaeological Overview Assessment

PEM output can guide archaeologists to sites that may have been important food sources for indigenous peoples, and can assist in planning a sampling strategy for Archaeological Overview Assessments.

☞ Exercise caution when using PEM for Archaeological Overview Assessments. Human beings' choices of habitat location are only somewhat predictable.

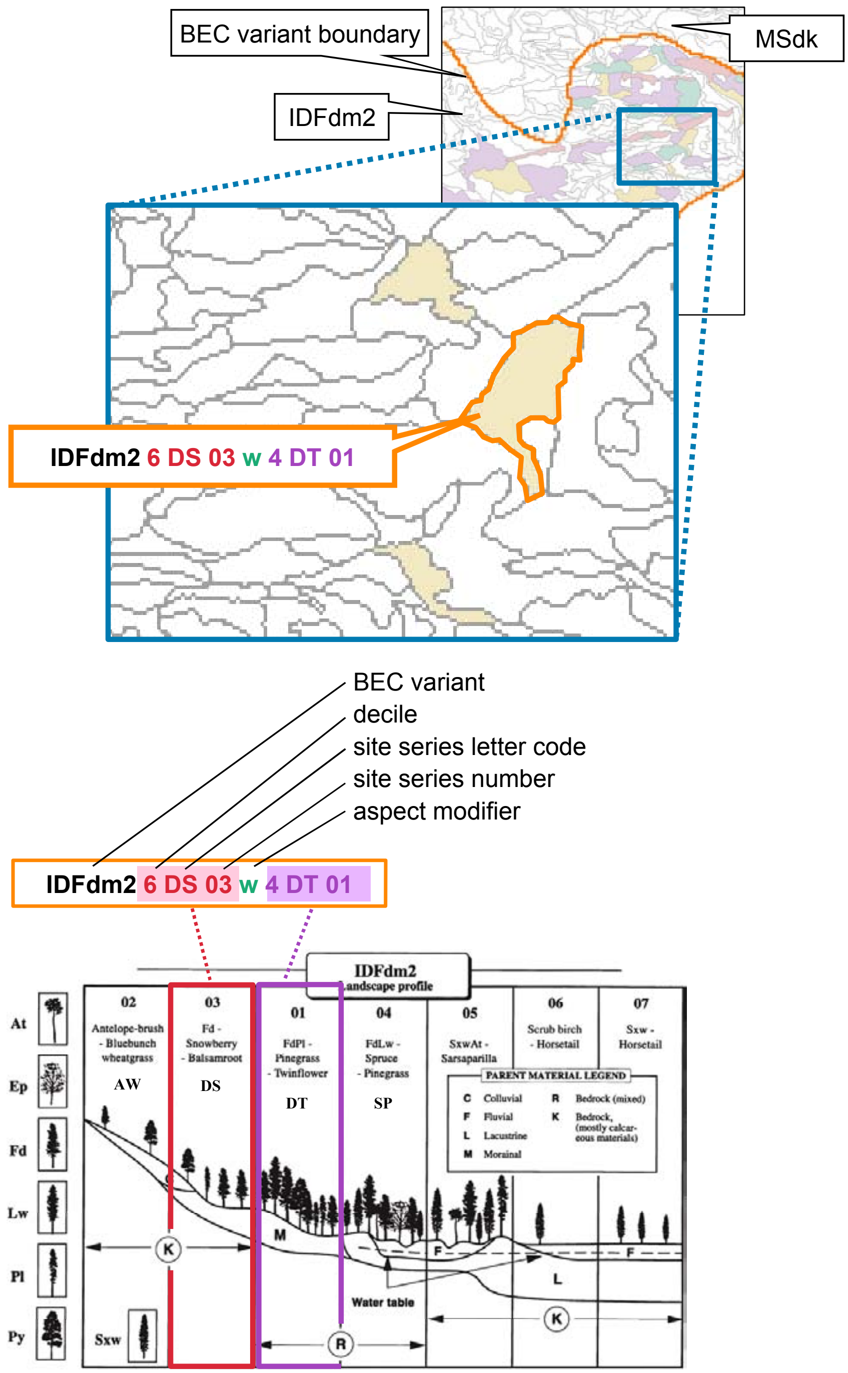
PEM could be used to assist in identifying areas that, in the opinion of a trained archaeologist, could have supported the living activities of early civilizations. Such interpretations assist archaeologists in the pre-stratification of the landscape into units with varying potential for evidence of utilization. This process is a requirement for some types of forest development planning.

Site series 03 (Fd-Snowberry-Balsamroot) of the IDFdm2 BEC variant is characterized by the presence of Balsamroot (*Balsamorhiza sagittata*). This common plant provided an important source of food to indigenous people. All parts of this plant are edible--leaves can be eaten or smoked, the taproots were roasted or steamed and dried, and the seeds were pounded and used like flour. Deer and elk graze on Balsamroot throughout the year. About 60% of the polygon shown in Figure 4-8 is predicted to support the growth of this culturally important plant.

Use PEM cautiously for this type of interpretation. PEM is directed at predicting ecosystems based upon features of site, climate and vegetation. Human beings' choices of habitat location are only somewhat predictable.

◆
The Fd-Snowberry-Balsamroot site series is characterized by the presence of Balsamroot (*Balsamorhiza sagittata*), an important source of food to indigenous people.

**Figure 4-8 Using PEM to delineate areas that may have supported food gathering by indigenous peoples.**



## 4.7 Spatially Distributed Process Models

*Note that this discussion is somewhat speculative. We thank Bob MacMillan of LandMapper Environmental Solutions for taking the time to make these observations.*

◆
PEM maps may be useful for supporting the application of physically-based or process models such as FORECAST by helping to scale up their predictions, and by providing some of the input data required to parameterize these models.

PEM maps may be useful for supporting the application of physically-based or *process* models such as FORECAST (Kimmins et al 1999)[41]. FORECAST is an ecosystem-based, stand-level, *forest growth simulator* which uses relatively simple measures of decomposition, nutrient cycling, light competition, and other ecosystem properties to simulate forest growth and ecosystem. It uses local growth and yield data (often from TASS/TIPSY) combined with other data to derive estimates of the rates of key ecosystem processes related to the productivity and resource requirements of selected species.

Assuming that FORECAST predictions can be made for individual or groups of site series, PEM maps can be used to help "scale up" the predictions from the individual locations or sites for which the detailed models have been run to other locations or sites with similar attributes, as associated with PEM ecological classes.

A second potential role for PEM maps in process modeling is to provide some of the input data required to parameterize these models. Most process models require a very large amount of information about a large number of site factors or conditions. One of the main challenges is to assign realistic and credible estimates of likely properties, conditions or states to each and every physical location for which the model is used to make a forecast. There is potential for consulting PEM maps and other similar types of maps to help prepare estimates of properties (e.g. porosity, depth, hydraulic conductivity, texture, litter thickness) and conditions (e.g. moisture content, depth to water table, temperature) for which a model equation is applied. PEM maps cannot supply all inputs required to run physically-based process models, but they can help improve estimates of many inputs.

There is real potential for PEM maps, and various ancillary data layers prepared in the construction of PEM maps, to be designed so as to maximize their utility as sources of input data for physically-based modeling.

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[41] Kimmins, J.P., Mailly, D., and Seely, B. 1999. Modelling forest ecosystem net primary production: the hybrid simulation approach used in FORECAST. Ecol. Modelling 122: 195-224.

On completing this section, users will understand:

- essential and optional data sources
- assessment of input data quality
- the function and importance of the knowledge base in a PEM
- format requirements and standards for PEM output.

# 5. Data Types and Attributes

PEM models use existing spatial inventory data to predict site series and structural stage. It is critical to understand which data sources are essential to the model and which are optional.

All PEM models require the most up-to-date BEC lines and the TRIM planimetric base for map registration. Additional sources of spatial data can be added to the model, depending upon financial resources and the interpretive needs of the client, as well as the quality and utility of the additional data to the model's predictive ability. The sources of input data for PEM can be in various formats, including vector, raster, and point.

This section overviews data sources commonly used in PEM models.

## 5.1 Spatial Inventory Input Layers

### 5.1.1 "Big BEC"

The biogeoclimatic ecosystem classification (BEC) is a hierarchical system that incorporates biotic (vegetation) and abiotic (climate and site) attributes at the provincial, regional, and site levels.[42] BEC lines are available from the MOF and are continually being refined and updated. The scale of provincial BEC mapping is generally 1:250 000. The lines are conceptual; they usually need to be refined for use in mapping and predictive models generated at scales of 1:20 000 to reflect local climatic and site conditions. The first step in the PEM process is to determine the suitability of the BEC lines and site series classifications based on their "vintage."

◆ The two critical spatial input layers for PEM are Big BEC and TRIM.

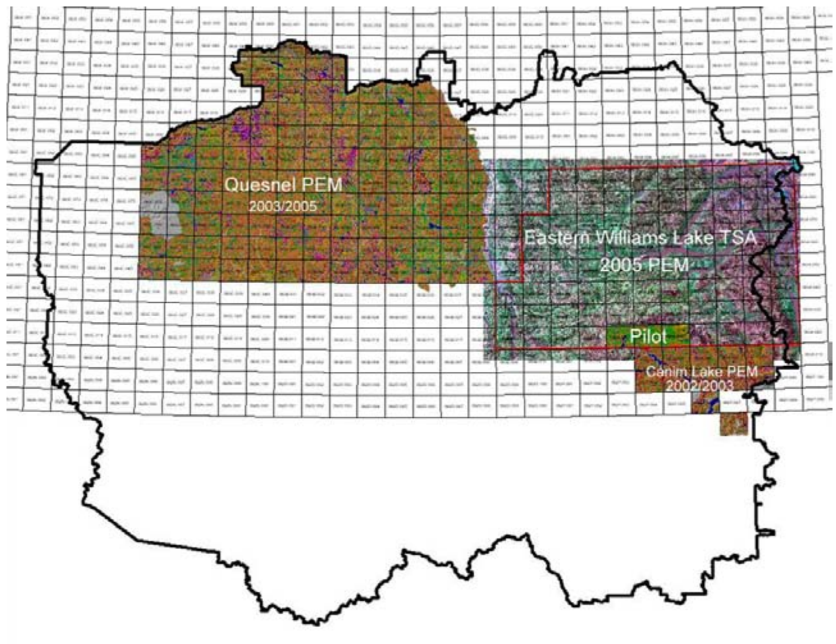
PEM is often preceded by "Big BEC" mapping,[43] which refines the legacy BEC mapping with large scale (1:20 000) BEC lines. Big BEC provides local climatic variation at an operational scale. MOF regional ecologists determine whether the "Big BEC" lines are suitable for the PEM process. Figure 5-1 shows the area in the Cariboo region mapped with Big BEC.

The biogeoclimatic subzone and variant lines mapped using the "Big BEC" process form the first level of stratification in a PEM model. It is the initial spatial stratification within which the model makes its prediction of site series.

[42] Meidinger, D. and J. Pojar (compilers and editors). 1991. Ecosystems of British Columbia. B.C. Min. For. Special Report Series No. 6. 330 p.

[43] Eng, M. and D. Meidinger. 1999. A method for large-scale biogeoclimatic mapping in British Columbia. Version 1.0. B.C. Ministry of Forests, Victoria, B.C. Available from: http://www.for.gov.bc.ca/hre/becweb/subsite-map/Bigbec.pdf.

**Figure 5-1 "Big BEC" in the Cariboo Forest Region; Big BEC provides local climatic variation at operational scales**




Source: Province of B.C.

### 5.1.2 TRIM

◆
One of the two critical inputs for a PEM model is a spatial inventory known as Terrain Resource Information Management (TRIM).

Terrain Resource Information Management (TRIM) is a spatial inventory that covers the province. The TRIM program produces digital maps, which is a collection of coverages to conform to the BC Geographic System layout.

A TRIM digital map contains positionally correct, complete, edited map data for a single map sheet. The data consist of all digital planimetric data compiled directly by stereo compilation. TRIM contains the following data that may be used in PEM models:

- *Digital elevation model (DEM)* — representation of the earth's surface as an array of elevations sampled at regularly spaced intervals.
- Raw contours — at a 20-m interval (derived from the DEM file).
- Non-positional — elevational control points, bridge deck, and tower heights, etc.
- Planimetric — all human-made features, such as roads, buildings, and fences, as well as natural features such as streams, lakes, and swamps.

- Toponymy — official place names, such as Prince George, Capilano River, etc.

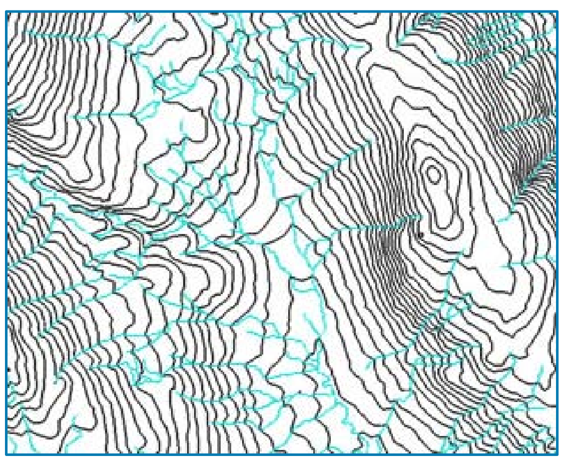
All models use the DEM and water features from the planimetric coverage. PEM standards require that the water features of the PEM be derived from the TRIM coverage (Figure 5-2); this ensures that the PEM output is registered to the TRIM water.

Other data from TRIM can be used during the PEM process for activities such as geo-rectification of typed air photos, creation of plot files, etc. Users should understand the strengths and limitations of the TRIM I and TRIM II coverage in their project area.

TRIM I mapping, completed in 1996, produced maps at a scale of 1:20 000. The cartographic framework for this mapping is the Universal Transverse Mercator (UTM) coordinate system, based on NAD83 (1983 North American Datum). The dimensions of each map sheet are 12 minutes of longitude by 6 minutes of latitude.[44]

TRIM I data have been updated in many areas of the province. TRIM II[45] improves upon TRIM I, but TRIM II also has some limitations that should be recognized by the PEM model. In some areas of the province TRIM II overestimates the amount of water on the landscape--for instance, in some stream networks produced by TRIM II a stream is allocated to every gully in areas where streams do not exist.

**Figure 5-2 TRIM elevation contours and water**



**The TRIM digital elevation model (DEM) provides:**

- slope class
- aspect class
- landscape position
- hydrologic flow
- etc

Source: B.C. TRIM data

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[44] British Columbia Specifications and Guidelines for Geomatics, Content Series Volume 3, Digital Baseline Mapping at 1:20 000 Release 2.0 January 1992.

[45] The new specification for TRIM II (1:20 000) and (1:10 000) Revision Data Capture Version 2.0, May 15, 1997.

### 5.1.3 Terrain Mapping

◆
Terrain mapping can be a useful input to PEM if it is at an appropriate scale and registered to TRIM planimetric features.

Terrain mapping, which delineates and classifies surficial materials, landforms and geomorphological process, can be a useful input to PEM if it is at an appropriate scale and registered to TRIM planimetric features. Variations of terrain mapping include bioterrain mapping and targeted terrain mapping (sometimes referred to as exclusions mapping).

#### Bioterrain Mapping

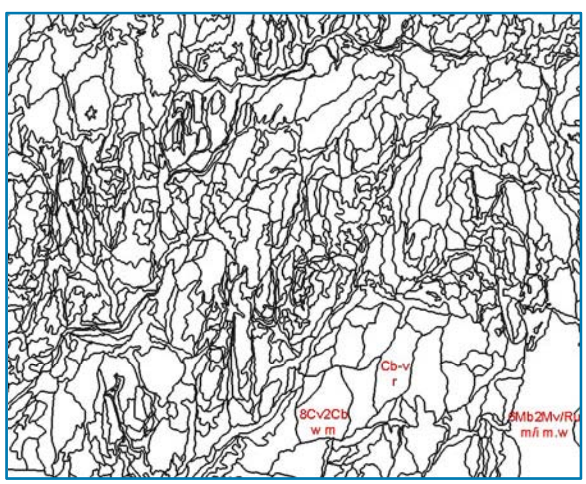
Bioterrain mapping uses the techniques and principles of terrain mapping, and also delineates aspect and soil moisture classes in the surficial materials, landforms, and geomorphological processes. Bioterrain mapping is not a prerequisite to PEM.

◆
Bioterrain mapping is not a prerequisite to PEM.

Some PEM models use bioterrain mapping as a spatial input data source. Bioterrain mapping gives polygon (vector) format information about terrain materials and their texture, origin, depth, slope, relevant geological processes, aspect, and drainage. Bioterrain variables are allocated within a complex polygon (Figure 5-3); the location of bioterrain attributes within the polygon is not known.

Some PEM models use the bioterrain polygon shape as the basis for the final PEM output. Most models that use bioterrain use only a few of the variables housed within the bioterrain database. The most commonly used variables from bioterrain describe materials that are atypical, such as very shallow materials, coarse materials, fine materials, very wet materials, organic deposits, active fluvial processes, or avalanche processes.

**Figure 5-3 Bioterrain map polygons**




**Bioterrain polygons are based on:**

- materials
- thickness
- aspect
- drainage
- process (disturbance)

**Bioterrain is a surrogate for:**

- soil moisture
- soil nutrients

Source: JMJ Holdings Inc. and Okanagan Innovative Forest Practices Society

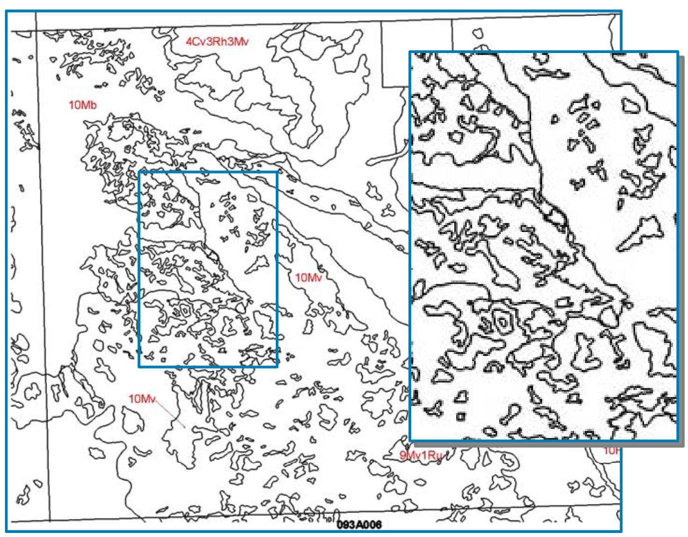
Bioterrain mapping is expensive and time consuming, but could be a valuable stand-alone inventory with potential for use in VRI. Bioterrain mapping is not a surrogate for Terrain Stability Mapping, which gives detailed information for some areas and general information for others.

### Targeted Terrain or Exclusions Mapping

◆
Some PEM models use mapping that only depicts the terrain attributes that are important for differentiating site series. In targeted terrain mapping, terrain attributes that are not useful to the model are not mapped.

Some PEM models use mapping that depicts only the terrain attributes important for differentiating site series (Figure 5-4). Terrain attributes that are not useful to the model are not mapped. This type of inventory is useful only for the PEM model, but is inexpensive and can be completed quickly. Targeted terrain mapping increases the ability of the PEM model to predict site series in situations where landscape shape and hydrology, as derived by the DEM, do not help the model differentiate between site series that occur in similar landscape positions. Targeted terrain polygons are generally simple polygons that do not describe attributes through proportions.

**Figure 5-4 Targeted terrain mapping delineates only the terrain attributes which help differentiate site series**



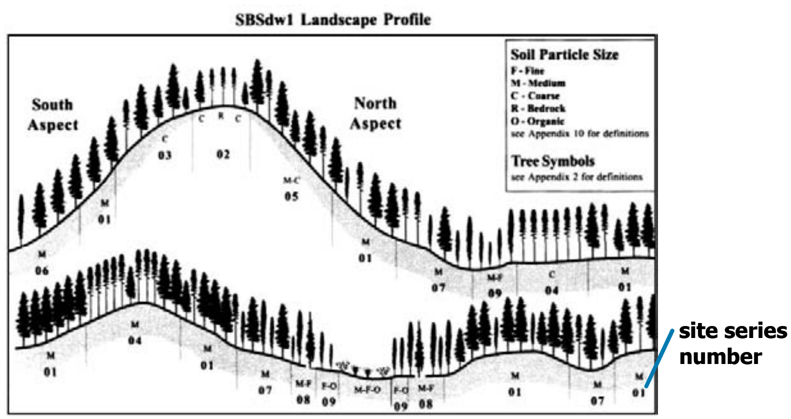

Source: JMJ Holdings Inc. and Okanagan Innovative Forest Practices Society

### 5.1.4 Landscape Facet Modeling

> ◆
> **Landscape Facets**
> Some PEM models use a raster analysis of the TRIM DEM to identify physiographic features based on landform position, relief class, slope length, slope gradient, and inferred hydrologic flow.

Landscape attributes important to the differentiation of site series within a PEM model can be modeled rather than mapped using data from the TRIM DEM. Some site series predictably occur in certain landscape positions (Figure 5-5). Some PEM models use a raster analysis of the TRIM DEM to identify physiographic subdivisions based on the size and scale of the landform.[46] The subdivisions interpret landform position, relief class, slope length, slope gradient, and inferred hydrologic flow. These attributes can help predict the amount of moisture available on the site, and the site series that may occur there. Other important landscape settings, such as local climatic variation (e.g., frost pockets), can also be predicted, where these are considered important to the differentiation of site series within a BEC subzone or variant.

**Figure 5-5 Landscape profile; most site series occur in predictable positions in the landscape**

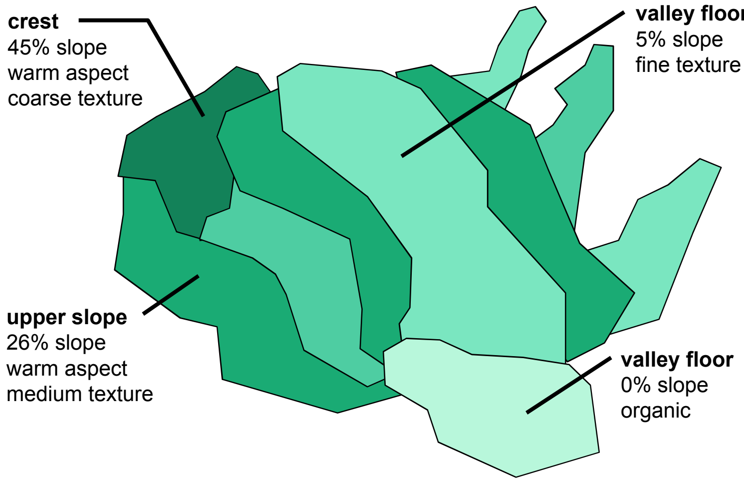



Source: Province of B.C.

This information, in combination with bioterrain or targeted terrain mapping, can improve the predictive ability of the PEM model. Errors in the TRIM DEM and stream network will be reflected in the output from the landscape facet model (Figure 5-6).

[46] MacMillan, R.A., M.V. Ketcheson, T. Robertson, K. Misural, J. Shypitka. 2003. Canim Lake PEM Final Project Report. Unpublished report to Weldwood of Canada.

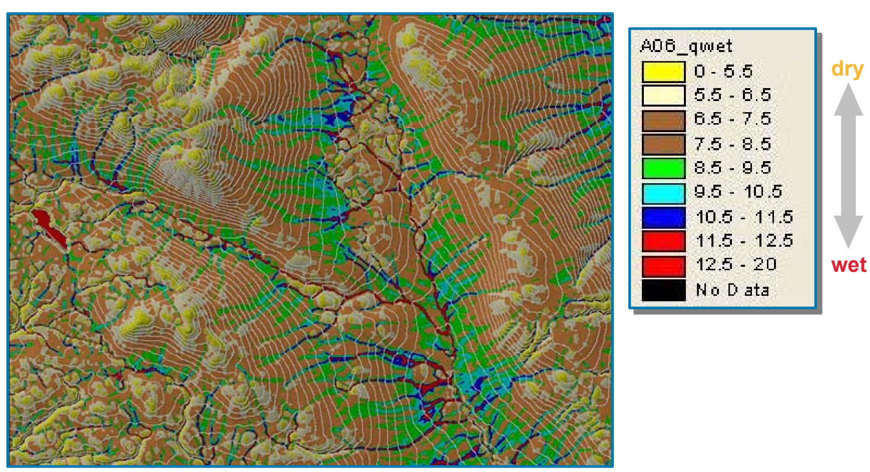
**Figure 5-6 Landscape facets**




### 5.1.5 Soil Moisture Models

Some PEM models use the TRIM DEM and stream network to predict soil moisture regimes using a *triangulated irregular network (TIN)*. These attributes can help predict the amount of moisture available on the site, and the site series that occur there (Figure 5-7). Errors in the TRIM DEM will be reflected in the result of the soil moisture model.

**Figure 5-7 Soil moisture predictions**




Source: LandMapper Environmental Solutions and Weldwood of Canada

### 5.1.6 Forest Cover or VRI

◆
Forest cover and VRI polygon data are often used in PEM models to help predict site series using tree species, presence of rock, non-productive brush, alpine, canopy closure, etc. It can also be used to predict stand structure.

Forest cover or Vegetation Resource Inventory (VRI) polygon data are often used in PEM models. In some models, PEM output polygon shape is based on forest cover polygons.

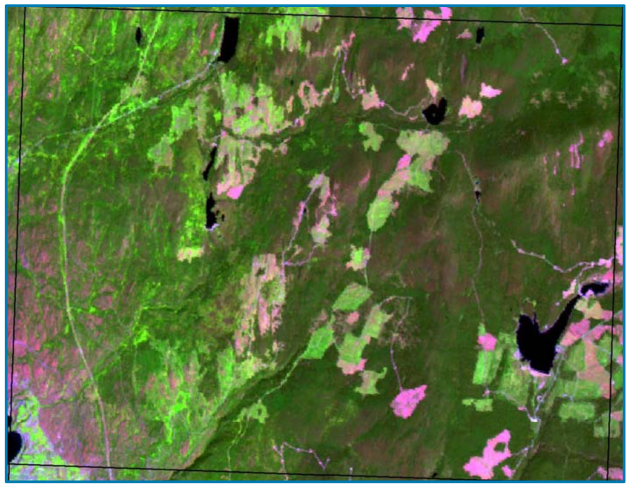
Forest cover polygons are based on tree species composition and site productivity. Forest cover data can also be used as a spatial input data layer in PEM to assist in the prediction of site series where the presence or absence of a tree species or combination of tree species helps define the site series. Other forest cover attributes can be used in a PEM model to aid in the prediction of site series, such as the presence of rock, non-productive brush, alpine, wetlands, open range, and canopy closure. Forest cover data can also be used in the structural stage portion of the PEM model. Attributes commonly used to predict stand structure include age, species composition, height, and history.

The format of VRI data is different than forest cover data, as are the number of variables available to the PEM model. The quality and detail of VRI data vary with the project, although VRI data must meet standards.

### 5.1.7 Satellite Imagery

Satellite imagery, which is in raster format, has been used in PEM to help differentiate physiognomic classes of vegetation (Figure 5-8). It can assist in the delineation of brush from forest, alpine tundra from krumholtz, graminoid wetlands from shrubby wetlands, and non-vegetated areas like recent cutblocks, rock, snow, and ice, from vegetated areas. The reliability of the satellite imagery needs to be determined before it is applied in the model.

**Figure 5-8 Satellite imagery**



**Satellite imagery is used in the delineation of:**

- bare soil
- rock
- trees
- shrubs
- roads

## 5.2 Input Data Quality Assessment

◆ Each spatial inventory used in PEM must be assessed for input data quality.

Each spatial inventory described in Section 5.1, and any additional spatial inventory used in PEM must be assessed for the quality of the data. The input data quality assessment report, a requirement of the PEM standards, must be completed for each set of spatial data used in the PEM model. The data must be reconciled to TRIM and positional accuracy reported relative to TRIM. Many PEMs use "retrofitted" FC1 forest cover data, which include reconciliation of the hydrographic features to the TRIM base. Retrofitted maps will pass the input data quality protocol, but do not permit evaluating the size of the original spatial errors or the spatial integrity of the lines that do not conform to the reconciled hydrography or control points.

The input data report provides general information about the PEM project, the area of interest, the data used, and their sources. The reports detail the method of data capture, quality assurance, quality control for spatial data, and any spatial reconciliation undertaken for the input data set, as well as any issues of importance relative to the use of that data. Table 5-1 presents an example of input data quality assessment.

**Table 5-1 Input data quality assessment example**

**2.0 TRIM II – TNTL Layer**

| | |
|---|---|
| **Citation:** | TRIM II Program |
| **Consultant/department:** | Geographic Data Branch, Ministry of Sustainable Resource Management |
| **Publication scale:** | 1:20 000 |

| | |
|---|---|
| **Period of compilation:** | 1997 |
| **Base map projection:** | Albers, NAD 83 |
| **Quality control:** | As per Table 1and Section 4.4.1.1. in the *Standards for Predictive Ecosystem Mapping in British Columbia, Inventory Standard, (RIC 1999)* the neatline features in the TRIM II data were considered to be of adequate quality to complete a PEM project at a scale of 1:20 000. |
| **Edge matching:** | No edge-matching was required. |
| **Edge matching error minimum:** | 0 m shift along the *x* axis, 0 m shift along the *y* axis. |
| **Edge matching error average:** | 0 m on the *x* axis. 0 m along the *y* axis. |
| **Edge matching error max:** | 0 m on the *x* axis. 0 m along the *y* axis. |
| **Attribute/label matching:** | All neatline boundaries contained the appropriate labels and attributes |
| **Raster sized:** | NA |
| **Adjusted control feature shift:** | None |

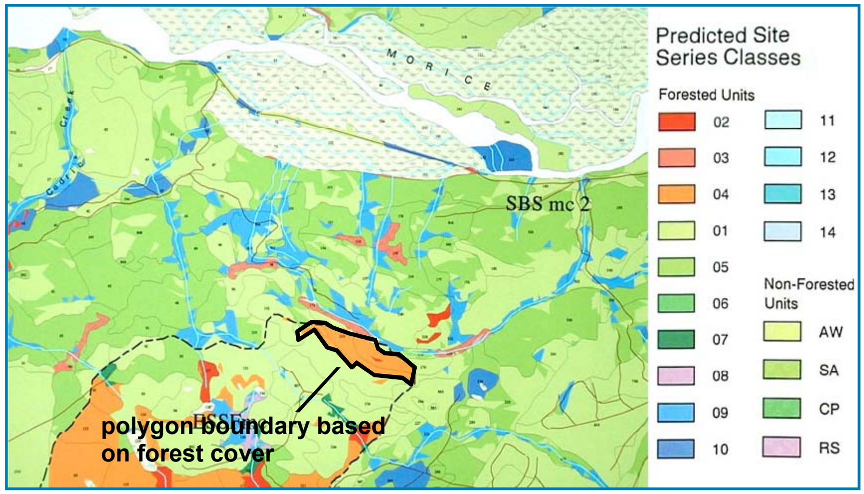
## 5.3 Output Data Format

### 5.3.1 Polygon Source and Format

The source of the final PEM polygon output shape can be derived from existing polygons, such as forest cover (Figure 5-9), bioterrain (Figure 5-10), or subdivisions of them, or the final PEM polygon shape can be derived from the output of the PEM model itself (Figure 5-11). The nature of the final polygons should be determined at the outset of the PEM project. The interpretations drawn from the PEM output should consider the source and format of the final PEM polygon shape.

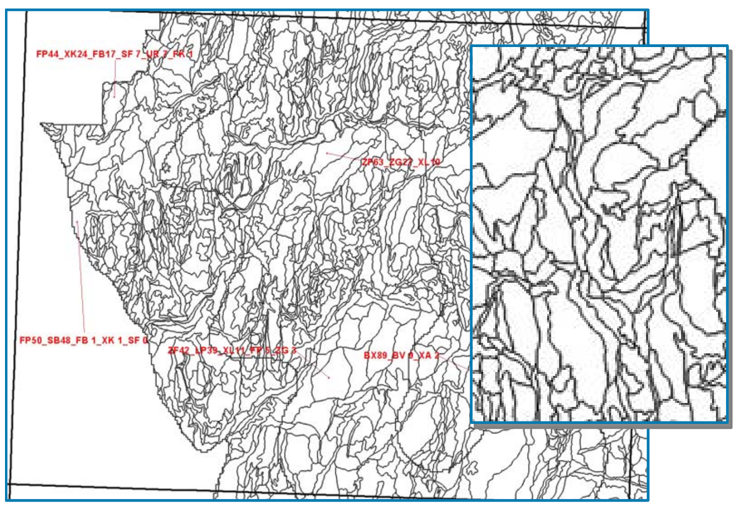
The final PEM output consists of a spatial coverage of polygons with a database describing the contents of the polygon. Depending on the PEM model the polygons can be simple or complex, small or large. Minimum polygon size is generally set at 1 ha. Usually no more than three site series are described within a polygon. Complex polygons do not spatially depict the location of individual site series; simple polygons do.

**Figure 5-9 Forest cover-based PEM**



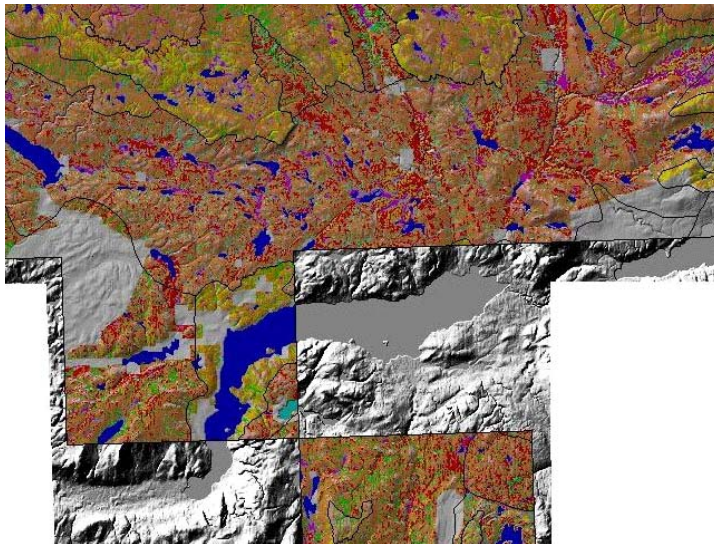

Source: Province of B.C.

**Figure 5-10 PEM polygon boundaries can be based on bioterrain**



Source: JMJ Holdings Inc. and Okanagan Innovative Forest Practices Society

**Figure 5-11 In raster-based PEM, polygon boundaries are based on raster cells with the same predicted site series**



Source: LandMapper Environmental Solutions and Weldwood of Canada

### 5.3.2 Map Entities Layer

◆
The final output of a PEM model gives the user only the BEC variant, site series, and modifiers for slope and aspect.

The format of the output of a PEM model is determined by client needs as revealed in the requirements analysis and, in the case of publicly funded projects, the PEM standards in place at the outset of the project. Generally PEM model output data base contains the following fields:

- **ECPtag**, which links the map entities database to the spatial polygon coverage
- **FCODE**, which identifies the feature code of the polygon linework
- **SRC_Fcode**, the source of the feature
- **Sdec1**, which identifies the decile proportion of the most common site series in the polygon
- **Site _S1**, the site series number of the most common site series in the polygon
- **Site series modifiers**, describing slope and aspect classes for the most common site series in the polygon.

The above are followed by Sdec_2, Site_S2, and modifiers for the next most common site series in the polygon and by Sdec_3, SiteS_3, and modifiers for the least common of the three site series identified in the polygon, if there are more than two. Table 5-2 shows an example record for the map entities layer.

**Table 5-2 Map entities layer for site series IDFdm2 6 DS 03 w 4 DT 01**

| Field | Example Entry | Description |
|---|---|---|
| ECPtag | 82L032_7858 | map sheet polygon number |
| FCode | WI25200100 | feature code for polygon |
| SRC_FCODE | | feature code assigned to digitally copied arcs to identify the source |
| Bgc_vrt | IDFdm2 | BEC variant |
| Sdec_1 | 6 | 60% decile (dominant ecosystem) |
| Site_S1 | 03 | site series number code, dominant ecosystem |
| Site_mcS1 | DS | site series letter code, dominant ecosystem |
| Site_m1a | w | modifier— "w" for warm |
| Site_m1b | | additional modifier if needed |
| Sdec_2 | 4 | 40% decile (second ecosystem) |
| Site_S2 | 01 | site series number code, second ecosystem |
| Site_mcS2 | DT | site series letter code, second ecosystem |

### 5.3.3 Structural Stage Layer

The structural stage layer of a PEM model predicts the structure of the stand using a classification approved by the regional ecologist and client at the outset of the PEM project. It is important that the client and PEM practitioner consider the interpretations to be made from the structure model before determining the classification. They also must consider the limitations of the input data sources used for the structure model. The structure codes used in the structural stage layer are shown in Table 5-3.

**Table 5-3 Structure codes used in the structural stage layer**

| Code | Structural stage description |
|---|---|
| 1 | sparse bryoid less than 10% vegetation cover |
| 2 | grass forb dominated |
| 3 | shrub dominated |
| 3a | low shrub dominated (<2 m) |
| 3b | tall shrub dominated (2 to 10 m) |
| 4 | pole sapling dominated |
| 5 | young forest dominated |
| 6 | mature forest dominated |
| 7 | old forest |

The final structural stage polygon can be derived in the same way as a site series polygon– through a knowledge base and spatial input data (see Section 5.3.1). The result can be a simple or complex polygon reflecting a single structural classification per polygon or up to three

structural classifications per polygon. The structural stage classification can be modified to suit the requirements of subsequent interpretations. The structural stage database is linked to the spatial polygon coverage by the ECP tag. Table 5-4 shows an example record for the structural stage layer.

**Table 5-4 Structural stage layer for IDFdm2 8723**

| Field | Example Entry | Description |
|---|---|---|
| ECPtag | 82L032_7858 | map sheet polygon number |
| FCode | WI25200100 | feature code for polygon |
| SRC_FCODE | | feature code assigned to digitally copied arcs to identify the source |
| Bgc_vrt | IDFdm2 | BEC variant |
| Sdec_1 | 8 | 80% decile (dominant structure in the polygon) |
| Strct_S1 | 7 | structure code for the dominant structure in the polygon— old forest |
| Sdec_2 | 2 | 20% decile (secondary structure in the polygon) |
| Strct_S2 | 3 | structure code for the secondary structure in the polygon— shrub dominated |

## 5.4 PEM Digital Data Standards

The output and documentation of a PEM model funded by government has to meet the PEM standards in place at the initiation of the PEM project.[47] Standards have evolved with the PEM process over the past decade; new standards are being proposed for implementation by 2006.

Information on the PEM standards is available from the PEM website: http://www.for.gov.bc.ca/hre/temalt/index.htm

[47] Resources Inventory Committee. 1999. The standards for Predictive Ecosystem Mapping in British Columbia, inventory standard. Victoria, B.C.

# 6. Limitations of PEM

## 6.1 Data Quality

On completing this section, users will understand:

- the implications of input data quality to the quality of the final PEM output
- examples of appropriate and inappropriate applications for PEM.

Data quality refers to 1) attributes of data that influence the suitability of input data sources for PEM, and 2) attributes of PEM outputs for business applications. These attributes of data quality have three basic components: content, precision, and accuracy, and apply to both thematic and spatial data.[48] Table 6-1 outlines the limitations of spatial data sources used in PEM.

The PEM model relies on input data to generate spatial and database outputs. Limitations of the input data must be realistically associated with the consequent limitations of the output PEM data and the applications made with that data. Although the spatial precision and accuracy of a PEM may be low, it nevertheless may predict the composition of site series in relatively small to large areas. This section identifies the limitations of spatial data sources, and discusses examples of appropriate and inappropriate uses of PEM data.

Section 6 discusses the main data sources for PEM: Big BEC, TRIM, Bioterrain, Targeted Terrain, Forest Cover, or VRI and field plot data. Other PEM projects use a variety of map sources, including geological mapping, satellite imagery, and soils mapping.

**Table 6-1 Limitations of spatial data used in PEM**

| Data source | Spatial limitations | Other data limitations | Consequences |
|---|---|---|---|
| TRIM I | DEM generalized, lacks micro-topographic details | Data source is 1:60 000 photography<br>Errors in wetland, shallow lakes and urban delineation and classification | PEM predictions may miss site series controlled by strong micro-topography, and predict an intermediate site series rather than the wetter and drier site series produced by the micro-topography. Unless the micro-topography is strong, the model can predict the correct site series for the area, but the spatial error of the small polygons can be tens of metres. [49]<br>Subdominant site series must be included proportionally as an element within the dominant site series based upon expert knowledge of micro-topographic elements in the landscape |

[48] Moon, D.E. 1999. Problem analysis on data quality assessment issues. Draft. Submitted to TEM Alternative Task Force by CDT Core Design Technologies Inc.

[49] Moon, D. 2005. Personal communication

| Data source | Spatial limitations | Other data limitations | Consequences |
|---|---|---|---|
| TRIM II | DEM generalized, lacks micro-topographic details<br>10 m contour intervals based on 1:60,000 photography | Overestimation of water in dry climatic areas | An indication of a stream within a gully when no stream exists increases the amount of wet habitat predicted by the model along the gully and at the bottom of the slope associated with the gully.<br>PEM using TRIM II will still have the same issues with micro-topography as TRIM I |
| Big BEC | May not accurately reflect BEC variant breaks in all areas when BEC lines are modeled from TRIM contours | | Accuracy assessment may find errors based on BEC variant distribution that are not a consequence of the PEM, as site series distribution along BEC boundaries may not reflect "typic" features. If BEC line is not correct, then the model's predictions in that area will also be in error. |
| Bioterrain | Complex terrain polygons do not locate individual components | Accuracy and reliability of photo interpretations | Terrain variability is not spatial at the polygon level; consequently, the PEM output may not reflect terrain variability accurately within the polygon.<br>A similar problem applies in a raster environment. Each cell derived from the terrain polygon will have proportions of relevant terrain assigned to it, making the raster PEM result aspatial within the cell. The ability to predict exact locations of site series based on terrain will be no better than with vector. |
| Targeted Terrain | Source orthophotos vary in quality and accuracy of orthorectification | Polygons may include small areas of other elements not noted in legend | Depending upon the heterogeneity of the targeted terrain polygons, expert knowledge must be used to include variability within the targeted terrain polygon and subsequent variability within the site series prediction. |
| Forest Cover | Spatial location of polygons may be suspect. | Accuracy and reliability of photo interpretations | Errors in variables such as species composition, crown closure, stand height, stand structure all result in errors in the PEM prediction where those variables discriminate between site series or structural stages. |
| VRI | Spatial location of polygons may be suspect | Data attributes may be modeled rather than photo interpreted | As above |
| Geological mapping | Scale is too small to provide accurate information at 1:20 000 | Geologic units may be complexes that are not spatially explicit | Site series predictions based on bedrock differences may be in error. |
| Soils mapping | Spatial reliability questionable | Soils units may be complexes that are not spatially explicit | Errors in location of terrain attributes will produce errors in the site series location prediction. Soils maps will have the same limitations as terrain and bioterrain maps. |
| Satellite imagery | | Imagery may yield same spectral quality for different substrates (e.g., rock and bare soil) | Inadequate training and testing of the imagery classification will lead to errors in the PEM prediction. |
| Field plot or transect data | May be spatially suspect, poor GPS data | Field classification of attributes may be erroneous | Even if spatially accurate, it is unlikely that field data will register exactly with other input data layers.<br>Errors in plot or transect UTM will result in erroneous assessment of the PEM result when plot data are compared with PEM output.<br>Errors in field attribute classification will result in an erroneous assessment of PEM input layer attributes and PEM site series result. |

## 6.2 Examples of Appropriate and Inappropriate PEM Data Applications

The successful application of PEM for natural resource management depends on the suitability of the PEM data for the particular interpretation. Although PEM data have many potential applications, not all are appropriate (Table 6-2).

**Table 6-2 Appropriate and inappropriate uses of PEM data for natural resource management**

| PEM application | Appropriate use of PEM data | Inappropriate use of PEM data |
|---|---|---|
| **Timber supply analysis** | Site index estimates | Identifying locations of individual site series within complex polygons (cutblocks). |
| **Wildlife habitat prediction** | Ungulate seasonal Capability/Suitability<br>Grizzly bear seasonal Capability/Suitability<br>Wetland dependent species Capability/Suitability<br>Grassland dependent species | Carnivore Capability/Suitability<br>Fur bearers Capability/Suitability<br>Species dependent upon small niche habitats<br>Some activity-specific habitat in micro-topographic positions |
| **Biodiversity objectives** | Thematic generalization of PEM BEC variants, site series, and structural stage output to drive seral stage distribution targets<br>**Stand structure interpretations should be made with caution–-the PEM stand structure model must be designed with biodiversity interpretations in mind.** | Stand structure interpretations for meeting biodiversity objectives that are based on a simplistic PEM structure model<br>Deriving stand structure interpretations from erroneous forest cover or VRI data |
| **Rare and Special Ecosystems** | PEM model should be designed with interpretation for rarity or special-ness as part of the algorithm.<br>**Rare and special ecosystems should be predicted with caution.** | Prediction of rare or special ecosystems that appear in micro-topographic locations beyond the resolution of the TRIM DEM<br>Overuse of small-scale geology mapping in prediction of rarity based on bedrock geology<br>Deriving rarity or special-ness interpretations from erroneous forest cover data |
| **Riparian Area Management** | A few riparian area attributes required by the Riparian Area Regulations[50] can be derived from PEM output. These include: active floodplain, floodplain plant species, and wetlands. | Predicting specific vegetation structures, coarse woody debris potential, stream channel morphology, etc. are beyond the scope of PEM. |
| **Archaeological overview assessment** | Archaeological Inventory Guidelines[51] require the description and use of BEC variant, vegetation, and forest cover and terrain mapping as part of the pre-stratification of the landscape for survey planning. Interpretations for pre-stratification of landscape elements suitable for "human habitat" using PEM output may be appropriate if designed by knowledgeable personnel. | PEM should not be used to predict the location of evidence of past use by First Nations. It is only useful for pre-stratifying the area of interest to assist in designing the inventory. |

[50] http://wlapwww.gov.bc.ca/habitat/fish_protection_act/riparian/documents/regulation.pdf

[51] B.C. Ministry of Small Business, Tourism and Culture. 2000. British Columbia Archaeological Inventory Guidelines. Version 1.0. Archeology Branch for the Cultural Task Force of the Resources Inventory Committee.

# Appendices

## Appendix 1: Acronyms

| | |
|---|---|
| AAC | allowable annual cut |
| BEC | biogeoclimatic ecological classification |
| DEM | Digital Elevation Model |
| ELDAR | Ecological Land Data Acquisition Resource system |
| FIA | Forest Investment Account |
| FSSIM | Forest Service Simulator |
| GWM | general wildlife measures |
| IWMS | Identified Wildlife Management Strategy |
| LRMP | Land and Resource Management Planning |
| MOF | Ministry of Forests |
| NDT | natural disturbance type |
| OGSI | Old Growth Site Index |
| PEM | Predictive ecosystem mapping |
| RIC | Resources Inventory Committee |
| RISC | Resources Information Standards Committee |
| RMA | riparian management area |
| SEI | sensitive ecosystem inventory |
| SIBEC | Site Index–Biogeoclimatic Ecological Classification |
| TEM | terrestrial ecosystem mapping |
| THLB | timber harvesting landbase |
| TRIM | Terrain Resource Information Management |
| TSR | Timber Supply Review |
| VRI | Vegetation Resource Inventory |
| UTM | Universal Transverse Mercator |
| UWR | ungulate winter range |

## Appendix 2: Glossary

***Accuracy***: the closeness of the presented value to the true value.

***Analysis unit***: in timber supply analysis, the aggregate of hectares which have the same species composition and site index, and will be managed in the same way, i.e., hectares which are assigned the same yield tables.

***Area-based***: with respect to timber supply analysis models, used to indicate that the relative location of each stand or cutblock (topology) is represented in the model. Also called spatially explicit.

***Big BEC***: revision of Provincial BEC lines to a larger scale (typically 1:20,000 or 1:50,000) suitable for use in PEM

***Biophysical***: using landscape shape or terrain mapping to predict the occurrence of an ecological entity, process or productivity

***Bioterrain mapping***: uses the techniques and principles of terrain mapping, and also delineates aspect and soil moisture classes within the surficial materials, landforms and geomorphological processes.

***Capability***: The ability of the habitat under optimal natural conditions to provide life requisites of a species.

***Complex map entity***: a map entity that represents more than one site series. It is used in situations where the PEM model cannot differentiate between two site series that occur together in a mosaic of micro-sites or where individual site series occur in very similar landscape positions.

***Data quality***: data quality attributes refer to: 1) attributes of data that influence the suitability of input data sources for predictive ecosystem mapping, and 2) attributes of predictive ecosystem mapping outputs for business applications. These attributes of data quality have three basic components: content, precision, and accuracy, and apply to both thematic and spatial data.

***Decile***: the proportion of each site series within a polygon, using increments of 10% and represented by a number between 1 and 10 such that 1 = 10% of the polygon and 10=100% of the polygon.

***Digital elevation model (DEM)***: a representation of the earth's surface as an array of elevations sampled at regularly spaced intervals.

***Ecosystem mapping***: the stratification of a landscape into map units, according to a combination of ecological features—primarily climate, physiography, surficial material, bedrock geology, soil, and vegetation.

***Entity***: a class or type of thing involved in the mapping process. An entity may be a site, site series, a soil, a polygon, a plant community, et cetera.

***Fuzzy logic***: A deductive system predicated on the notion that truth is a multi-valued, continuous quantity. It allows for the concept of partial truth – truth values between "completely true" and "completely false". It might be more correctly called "continuous logic".

***Geo-referenced data***: located by a system of coordinates, usually by GPS; can be in the Universal Transverse Mercator (UTM) or longitude and latitude systems.

***Knowledge base***: in the context of PEM, the formal expression of the rules used to predict site series from ecological attributes; the knowledge base comprises both the set of data tables mapping the relationships between ecological attributes and site series and the algorithms used to interpret the data and relationships to predict site series.

***Landscape facet***: a distinct feature, or element of landscape.

***Low site***: in timber supply analysis in British Columbia, a category of site productivity applied to stands considered not productive enough for timber harvesting and management.

***Map-entity***: is the basic ecosystem element being mapped e.g., Ecosection, Biogeoclimatic Zone, subzone/variant/phase, or site series/structural stage/modifier/seral community type. It can be simple or complex.

***Map-feature***: a point, line or polygon representing a site, linear feature, or area on a map. Map features may be labelled with multiple map-entities.

***Map unit***: see map entity.

***Meta-data***: data describing data; meta-data describe the content, quality, condition, and other characteristics of the data of interest.

***Precision***: used here in the non-statistical sense of exactness or fineness of resolution with which a feature or property is described. While in some degree related, the statistical definition refers to the standard error or repeatability of measurement not the exactness or resolution of the measurement. Some statistical textbooks use the terms precision and reliability as synonyms, which is not the usage here (Moon 1999).

***Predictive ecosystem mapping***: a computer-, GIS-, and knowledge-based method of stratifying the landscape into ecological map units, typically site series.

***Rare ecosystems***: ecosystems labelled as red- or blue-listed by the Conservation Data Centre of the Ministry of Sustainable Resource Management.

***Reliability***: thematic and spatial accuracy and precision; one component of data quality.

***Simple map entity***: a map entity representing a single site series.

***Site index***: a measure of potential site productivity—the capacity of an area of land to grow trees of a given species. A simple definition is the height of dominant trees at age 50.

***Site series, BEC***: all sites capable of producing the same mature or climax plant communities within a biogeoclimatic subzone or variant.

***Spatially explicit***: Not formally defined, but usually used in the context of timber supply analysis to mean that the location of stands or cutblocks with respect to one another (topology) is represented in the model.

***Special ecosystems***: ecosystems considered rare or unique, uncommon, interesting, sensitive, or of concern.

***Stand structure***: see structural stage

***Structural stage***: the seral status of the site series based on a simple classification of overall stand structure, one of: bryoid, grass forb, shrub, pole sapling, young forest, mature forest, old forest.

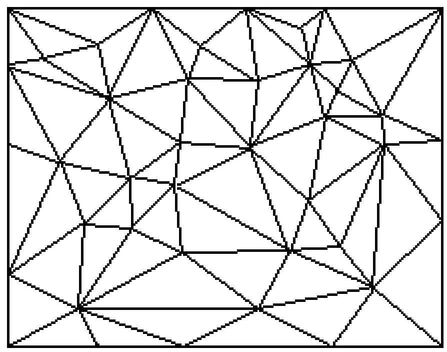
***Suitability***: the ability of the habitat in its current condition to support the species.

***Timber harvesting land base***: in timber supply analysis, the area considered available for timber harvesting; alternatively, the hectares on which timber harvesting is allowed in the timber supply model.

***Timber supply***: the volume of timber made available for harvesting annually; measured in units of cubic metres per hectare.

***Timber supply analysis***: a process for estimating timber supply.

***Triangulated irregular network (TIN)***: a form of digital elevation model based on irregularly spaced nodes, in which each sample point has X-, Y- co-ordinates and a surface, or Z-value. These points are connected by edges to form a set of non-overlapping triangles which represent the surface. Unlike a grid, the TIN allows dense information in complex areas, and sparse information in simpler or more homogeneous areas.



An example of a triangulated irregular network (TIN)

***Variant, BEC***: A subdivision of subzone based on differences in regional climate. There can be considerable climatic variability within subzones--subzones may be further subdivided into areas that are slightly drier, wetter, snowier, warmer or colder within the subzone.

***Wildlife habitat ratings***: a classification system describing the ability of a habitat to meet the life requisites of a species or group of species.

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# Appendix 4: Information Sources

## EcoGen

http://www.for.gov.bc.ca/hre/ecogen/

## PEM (TEM Alternatives)

http://www.for.gov.bc.ca/hre/temalt

## TEM & PEM Home Page

http://srmwww.gov.bc.ca/ecology/tem/index.html

## Problem Analyses of the TEM Alternatives Task Force

http://www.for.gov.bc.ca/hre/temalt/public.htm

## Standards

http://srmwww.gov.bc.ca/ecology/tem/manuals.html

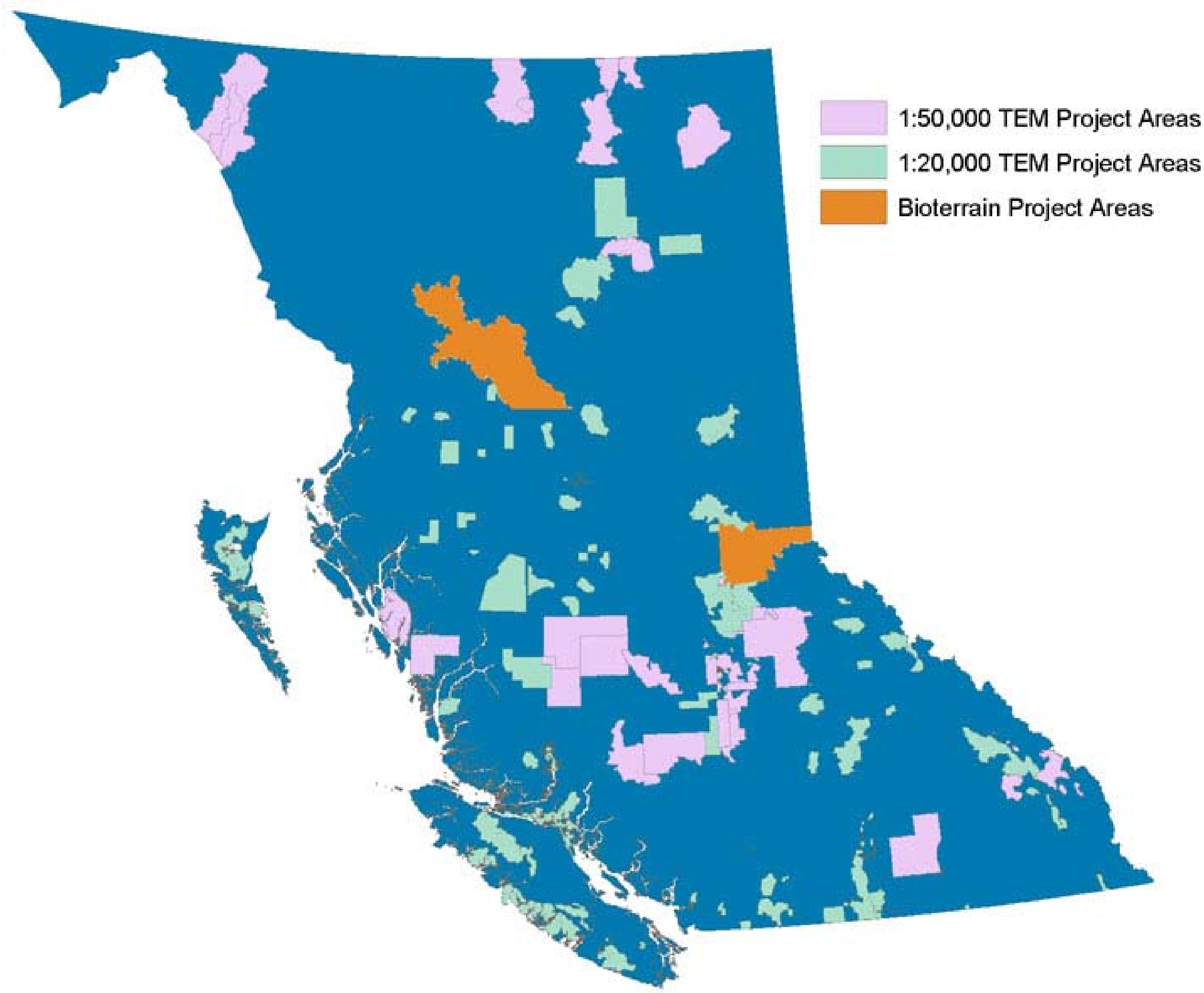
## TEM

http://srmwww.gov.bc.ca/rib/wis/tem/

## VRI Ecosystem and Habitat Mapping

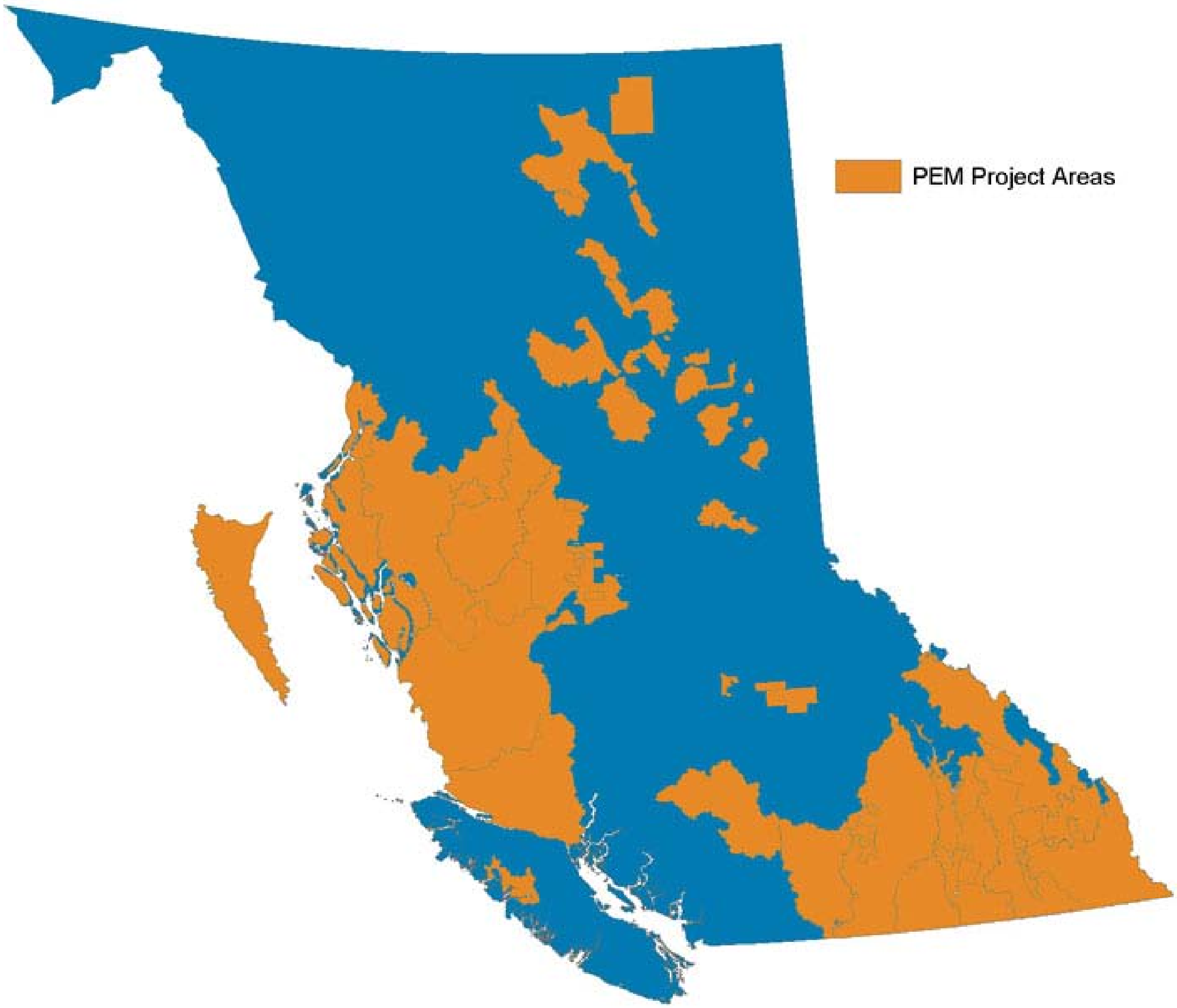
http://srmwww.gov.bc.ca/rib/wis/vriehm/

# Appendix 5: TEM projects in British Columbia




Source: Province of B.C.

# Appendix 6: PEM projects in British Columbia




Source: Province of B.C.

# Appendix 7: Frequently Asked Questions

## What is the difference between vector- and raster-based PEM models?

The rules used to convert real geographical variation into discrete objects (points, lines, polygons) is referred to as a data model—a set of guidelines for organizing the data in a database. All PEM models are based on either raster (grid) or vector (polygon) data models, or a combination of both.

In a raster data model, the mapped area is divided into a regular grid of cells. Every location in the mapped area corresponds to a cell in the raster. Discrete objects are represented as single cells or groups of related cells.

In a vector data model, the location of a discrete point in the mapped area is identified with reference to map co-ordinates (x, y). Discrete objects are represented as points (single locations), lines (groups of related points), or polygons (groups of related lines). A separate database contains the descriptive attributes of the objects, with an index linking each object to a record in the database.

Data can be converted from raster to vector and vice-versa, so the choice of data model is an issue for the modeler, since it affects the ways in which the data are used, but not for the client, who is really interested in applying the results.

## What is a map entity?

A map entity is the thing that is mapped, which in PEM is the site series.

## What's the difference between a simple polygon and a complex polygon?

A simple polygon contains only a single site series or map entity. A complex polygon can have up to three site series or map entities that are allocated proportions of the polygon (e.g., 50%, 35%, 15%).

## Is bioterrain mapping a required element of a PEM model?

Bioterrain mapping, or any type of terrain mapping, may be used in a PEM model but is not required.

## What is Big BEC, and why is it important when undertaking a PEM project?

"Big BEC" refers to revised BEC lines that better reflect local variation in climate at scales of 1:20,000 or 1:50,000. The distribution of local site series is better reflected in a PEM when the BEC lines have been updated using the Big BEC protocol.

## Does PEM require field data for model building?

Field data may be collected for use in PEM model-building activities, but is not required. See Section 3.4.2 of the User's Guide for information on how field data can be used to test the knowledge base.

## What is the difference between accuracy and reliability?

Reliability, which comprises accuracy and precision, is the probability of a specific interpretation not being wrong; it is relative and context-dependent. Accuracy is the closeness of a presented value to the true value. Precision is the exactness of measurements or predictions.

The reliability required for any project is a function of the sensitivity of interpretive or predictive procedures, and the consequences of errors. If small changes in input values cause large responses in predicted values, the requirement for precision is high. Conversely, if large changes in input values cause small responses in predicted values, the requirement for precision is low. If the consequences of predictive error are low, the need for accuracy is low, whereas if the consequences of error are high, high accuracy is needed.

Accuracy standards and protocols for accuracy assessments have been developed for using PEM in critical applications such as the Timber Supply Review. See Section 3.6 of the User's Guide for more information.

## Why doesn't my PEM give me a map?

PEM output consists of spatial files and a database. If the client wants a printed map the spatial data and database have to be linked and queried to produce a "plot file" which depicts the elements of the database the client wants to see on a map. Standard PEM output does not include map plot files. If a requirement, map production should be specified in the requirements analysis phase of the project.

## Can the vector-based standard output stored in the provincial data warehouse be subsequently rasterized?

Yes, a polygon can be "shattered" back into grid format. The data attached to each raster cell will retain the complexity of the original polygon. If a complex polygon is rasterized, **each cell** will also have the same group of site series as the original polygon. Rasterization cannot render aspatial attribute data spatial.

## Why does the PEM data base contain both a number and letter code for site series?

Early in the development of ecosystem mapping standards the BC Ministry of Environment (MOE) used two-letter codes for ecosystems while the Ministry of Forests (MOF) used numbers. When the two agencies cooperated to create mapping standards they retained both

systems of naming site series because the MOE two-letter codes describe site series for some non-forested ecosystems to which MOF codes have not been assigned (MOF code is 00). A list of the acceptable two-letter codes can be obtained from the Ministry of Sustainable Resource Management at the following web site:

http://www.for.gov.bc.ca/hre/becweb/standards-becdb.htm

### Are the provincial PEM standards being revised?

Yes. Revised standards are expected in 2006.